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# PHYSICAL CHARACTERISTICS OF CHAMISE AS A WILDLAND FUEL

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Energy from burning fuel is the primary driving force for the fire behavior phenomena observed in wildland fires. Physical characteristics of the fuel elements and their arrangement in the fuel bed are important determinants of the amount of energy available and the rate at which it is released. For example, finely divided fuels, such as pine needles or excelsior, release their energy quickly. Large timbers or logs usually burn slowly and may require hours to release all of their potential energy. Quantitative evaluations of the fuel complex are essential to progress in the control and use of wildland fire.

Physical characteristics of fuels and fuel beds now recognized as influencing fire behavior include:

1. Distribution of fuel in the fuel bed, by size and condition (live or dead).
2. Fuel loading ($W_a$): fuel weight per unit of fuel bed area.
3. Fuel density (d): fuel weight per unit of fuel volume.
4. Fuel surface-to-volume ratio ($\sigma$).
5. Fuel bed porosity ($\gamma$): ratio of fuel bed volume to fuel volume. The *packing ratio* ($\beta$), the converse of fuel bed porosity, is the ratio of fuel volume to fuel bed volume.
6. Moisture content of fuel.
7. Heat content of fuel.
8. Chemical composition of fuel.

At present, many of these characteristics can be determined only by direct physical measurement and calculations made from such measurements. Others can be determined by laboratory procedures. In varying degree, all influence such fire phenomena as ignition time, rate of spread, burning time, and intensity. Procedures for estimating physical characteristics of fuels are not well developed. In an operational situation, such as a going fire, the fire manager needs a quick way of estimating fuel characteristics so that he can forecast probable fire behavior.

In southern California, one of the most hazardous wildland fuels is chamise *(Adenostoma fasciculatum)*. This common, aggressive shrub grows in pure stands or in mixture with other chaparral species in the mountains of southern California, throughout the Coast Ranges, and in the lower Sierra Nevada foothills *(fig. 1)*. Chamise probably has a wider range and produces more volume of growth than any other shrub in California (Sampson and Jesperson 1963).

Chamise is a medium-sized, evergreen shrub usually 2 to 8 feet tall when mature, but occasionally taller. The shrub has many slender, rigid branches covered with clusters of needlelike leaves ¼ to ½ inch long *(fig. 2)*. The leaves are often resinous. The bark is gray or dark-colored, and usually shreddy. Generally, little leaf litter is produced, but under severe drought stress, chamise may shed much of its foliage.

At low elevations new growth usually starts in January, increases rapidly in April and May, and slows or stops in June (Hanes 1965). The beginning of the growth cycle is often delayed at high elevations. After a fire, there is abundant sprouting from the root crowns, and seedlings are numerous. There are few seedlings in dense mature stands, however, and little other vegetative growth.

Besides studying the physical characteristics of chamise, we were interested in the interrelationships of various shrub characteristics. We wanted to find some means of estimating these characteristics in the field with a minimum of measurements. How fuel characteristics affect fire behavior is known in a general way. But explicit relationships for the most part have not been established, particularly for the combinations of fuel factors as they occur naturally. Thus, the precise amount of change needed to produce a significant change in fire behavior is not known. Nevertheless, available information suggests the relative importance of the various fuel characteristics, and the accuracy of the estimates needed. But before standards for accuracy can be set, we need to establish explicit relationships between fuel characteristics and fire behavior.

This paper reports a study of the physical characteristics of chamise as a wildland fuel. It considers their effects on fire behavior and the quantitative values found in a study of chamise. It describes methods of estimating some of the less easily measured characteristics of this shrub, and evaluates the reliability of these techniques.

Most of the quantitative data reported for chamise are from an analysis of 16 shrubs from the North Mountain Experimental Area, 30 miles east of Riverside, California. But where appropriate, we have included data obtained by other investigators.

Figure 1—*Chamise, a highly flammable shrub species, grows throughout the Coast Ranges and lower Sierra Nevada foothills of California.*

Figure 2—*Chamise foliage consists of slender branches covered with needlelike, often resinous leaves in fascicles of 10 to 15.*

## PROCEDURES

### *Collection and Dissection*

The 16 shrubs analyzed were selected by a systematic random-sample method at 4,000 feet elevation. Chamise made up about half the vegetation on the site, the rest consisting of other common chaparral species.

The shrubs were collected two or three at a time from June 1964 through May 1965. The shrub height and average crown diameter at its greatest development were measured with the shrub in place. It was then cut off at ground level and wrapped in canvas to prevent loss of any material during transport to the laboratory. There the shrubs were immediately hung

in individual sheet-plastic-lined stalls. Dead portions were tagged so that they could be identified when the shrubs became dry.

The material in each shrub was removed in five groups representing the following size classes:

1. Foliage
2. Woody material less than ¼ inch in diameter
3. Woody material ¼ to ½ inch in diameter
4. Woody material greater than ½ inch to 1 inch in diameter
5. Woody material greater than 1 inch in diameter.

## Measurement of Leaves

The shrubs were allowed to dry for about 2 weeks at 70°F. before dissection was started. Leaves were then removed with a jet of compressed air, and collected from the bottom of the stall with a vacuum cleaner. Extraneous material was removed with an air-blower-type seed cleaner. The leaves were then weighed and samples were removed for moisture-content determination. On the basis of the average moisture content of these samples, the leaf weight was adjusted to dry weight.

The needlelike leaves of chamise are in fascicles of 10 to 15. The surface area and volume of broad-leaved species can be determined readily by direct measurement, but needlelike leaves present a problem and some geometric shape must usually be assumed (Kozlowski and Schumacher 1943; Kumagi 1962; Madgwick 1964). The surface area and volume of chamise leaves was estimated by assuming a circular cross section and combined shape of three frustrums and a cone. This geometric simulation is shown against a photographic outline of a leaf in *figure 3*. Three one-quarter diameters, the end diameter, and total length were determined by a measuring magnifier. Three samples of 25 leaves each were used to obtain average values for chamise leaves.

## Measurement of Woody Material

As material each size class was clipped from the shrub, it was separated into live and dead groups and measured for length. All of the shrubs contained a large amount of material in the smallest size class, so length measurements were made on a 30 percent (by weight) subsample. For the larger size classes all of the material was measured.

The live and dead material was weighed separately and samples of each were withdrawn for moisture-content determination, so that the dry weight of the material could be calculated.

On the assumption that all of the woody material was cylindrical in shape, the surface area and volume were calculated from dry weight, total length, and average density of the material in each size class by use of the equations:

$$V = W/d$$
$$A = 2\pi L\sqrt{(W)/(d\pi L)}$$

in which

V = volume
A = Area
d = Density
W = Dry Weight
L = Length.

The average wood densities used in the calculations were derived from samples taken from five shrubs. Five samples from each size class of live and dead material were taken from each shrub. Symmet-

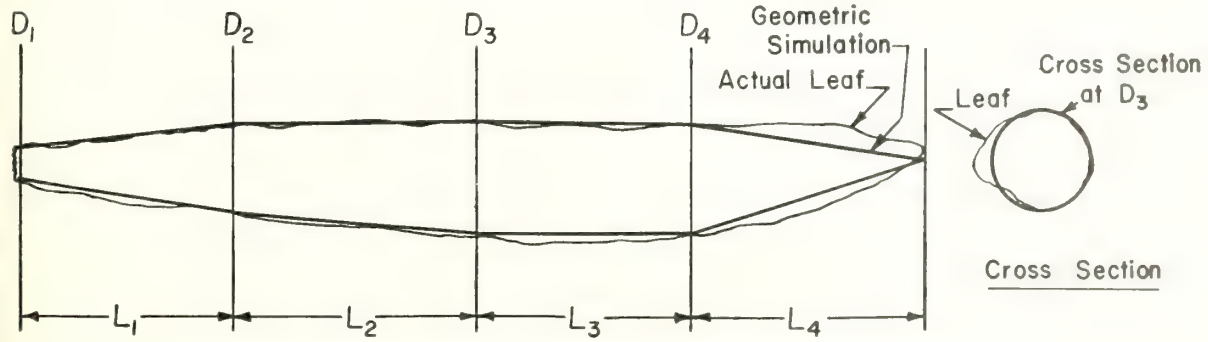


Figure 3–*Geometric simulation of a chamise leaf, shown in comparison with its actual shape, was used to determine surface area and volume.*

rical pieces of wood varying in length from 1 to 2 inches were chosen. Each sample was carefully measured for length and diameter and the volume calculated. Volume of the samples was also determined by the water displacement method. Average volumes as determined by both methods agreed closely; however, the displacement method appeared to give more consistent results, and these were used in the density calculations.

The fuel samples were ovendried to obtain their dry weight. The density of live material was calculated for both the green wood and dry wood volumes. However, to conform to the usual practice for wildland fuels, the density based on green wood volume and dry weight was used in the equations for volume and area determination. The wood density for the live material increased as the wood diameter increased. However, density for a given size class of material differed only slightly between shrubs.

The density of the dead material for each size class varied greatly, not only among shrubs but within a shrub as well. Examination of the samples indicated that they were in different stages of decomposition. The density of dead wood in a good state of preservation was close to that of living material calculated from its dry volume. The density of weathered samples was less–the amount apparently depending upon the degree of decomposition. Unfortunately, no attempt was made to segregate the dead wood by condition when the shrubs were dissected. Average density of the dead material was hence estimated from the material available, and these values were used for calculation of the dead wood volume and surface area.

The results of the chamise shrub measurements and calculation of volume and surface area are summarized in *table 1*.

Table 1–*Dimensions of 16 chamise shrubs analyzed*

| Shrub number | Height | Crown diameter | Fuel weight | Fuel surface area | Fuel volume |
|---|---|---|---|---|---|
| | — *Feet* — | | *Pounds* | *Sq. ft.* | *Cubic ft.* |
| 1 | 6.0 | 4.1 | 9.32 | 133.7 | 0.2299 |
| 2 | 5.8 | 3.4 | 5.02 | 42.3 | .1130 |
| 3 | 8.0 | 5.0 | 21.98 | 234.1 | .5144 |
| 4 | 4.2 | 3.2 | 4.06 | 81.5 | .1018 |
| 5 | 6.5 | 4.5 | 4.83 | 67.2 | .1161 |
| 6 | 5.0 | 3.9 | 4.41 | 68.0 | .1076 |
| 7 | 7.0 | 5.2 | 9.44 | 165.1 | .2325 |
| 8 | 8.5 | 8.0 | 12.63 | 142.0 | .2888 |
| 9 | 7.3 | 7.0 | 10.79 | 111.0 | .2462 |
| 10 | 4.5 | 4.2 | 2.44 | 40.1 | .0566 |
| 11 | 4.4 | 3.5 | 2.77 | 31.3 | .0629 |
| 12 | 6.3 | 3.0 | 5.66 | 75.5 | .1329 |
| 13 | 3.4 | 2.2 | 1.54 | 66.7 | .0466 |
| 14 | 3.0 | 3.0 | 3.07 | 110.5 | .0895 |
| 15 | 3.0 | 3.0 | 2.06 | 37.9 | .0515 |
| 16 | 6.3 | 3.0 | 2.34 | 53.2 | .0597 |

# FUEL CHARACTERISTICS

Using the procedures described earlier, quantitative values for the characteristics of the 16 chamise shrubs were tabulated. The necessary calculations, as well as the results themselves, are described in the following sections.

## Size-Class Distribution

Tabulation of the weight, volume, and surface area of the material showed that the proportion of small material was not consistent among the shrubs *(table 2)*. The percentage of weight, and hence volume and surface area also, represented by the small material varied widely. For example, the weight of the foliage ranged from a low of 5.6 percent to a high of 36.5 percent. These tabulations also show the influence of the smaller material on the total surface area of a fuel bed. About 13 percent of the weight and 23 percent of the volume on the average was in the foliage. However, the average for surface area of the foliage was more than 67 percent of the total.

Observations have indicated that wildfires in chamise usually do not consume material larger than one-half inch in diameter. Thus the proportion of smaller fuels is highly important in determining the behavior of chamise fires. About 61 percent of the fuel weight and 65 percent of the fuel volume of the shrubs was in the fuel one-half inch or less in diameter. Nearly all of the surface area (96 percent) in these fuel sizes.

## Amount and Distribution of Dead Fuel

Living fuels usually contain large amounts of moisture and hence do not burn well by themselves. However, in most wildland fuels dead fuel is intermixed with the living fuel. Under appropriate

Table 2–*Distribution of fuel weight, volume and surface area in chamise, by size classes*

| Material size (inch) | Shrub number | | | | | | | | | | | | | | | | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | |
| | WEIGHT (PERCENT) | | | | | | | | | | | | | | | | |
| Foliage | 12.5 | 5.7 | 8.7 | 15.1 | 10.9 | 12.2 | 13.2 | 6.8 | 6.4 | 7.3 | 5.6 | 9.2 | 36.5 | 30.2 | 13.7 | 16.5 | 13.2 |
| <1/4 | 19.8 | 16.6 | 19.3 | 32.8 | 22.4 | 20.2 | 23.7 | 18.3 | 19.7 | 32.7 | 30.0 | 23.5 | 31.1 | 40.4 | 33.9 | 32.0 | 26.0 |
| 1/4 - 1/2 | 16.2 | 18.6 | 21.8 | 24.9 | 17.6 | 35.7 | 20.0 | 22.5 | 22.6 | 19.8 | 26.9 | 13.6 | 23.3 | 13.7 | 28.4 | 19.3 | 21.6 |
| 1/2 - 1 | 35.5 | 41.5 | 30.6 | 16.9 | 46.8 | 31.9 | 43.1 | 35.2 | 28.2 | 40.2 | 18.8 | 25.0 | 9.1 | 15.7 | 24.0 | 30.0 | 29.5 |
| 1 - 3 | 16.0 | 17.6 | 19.6 | 10.3 | 2.3 | 0 | 0 | 17.2 | 23.1 | 0 | 18.7 | 28.7 | 0 | 0 | 0 | 2.2 | 9.7 |
| | VOLUME (PERCENT) | | | | | | | | | | | | | | | | |
| Foliage | 23.4 | 11.5 | 17.0 | 27.4 | 20.7 | 22.6 | 24.4 | 13.5 | 12.8 | 14.2 | 11.2 | 17.9 | 54.8 | 47.2 | 24.8 | 29.3 | 23.3 |
| <1/4 | 17.9 | 16.2 | 18.2 | 28.5 | 20.5 | 18.2 | 21.1 | 17.6 | 19.0 | 30.4 | 28.9 | 21.9 | 22.4 | 31.2 | 30.2 | 27.7 | 23.2 |
| 1/4 - 1/2 | 14.3 | 17.6 | 19.9 | 21.4 | 15.6 | 31.4 | 17.4 | 21.1 | 21.1 | 18.3 | 25.4 | 12.5 | 16.5 | 10.2 | 24.6 | 16.1 | 18.9 |
| 1/2 - 1 | 30.8 | 38.7 | 27.5 | 14.3 | 41.1 | 27.8 | 37.1 | 32.2 | 26.0 | 37.1 | 17.4 | 22.2 | 6.3 | 11.4 | 20.4 | 25.1 | 26.0 |
| 1 - 3 | 13.6 | 16.0 | 17.4 | 8.4 | 2.1 | 0 | 0 | 15.6 | 21.1 | 0 | 17.1 | 25.5 | 0 | 0 | 0 | 1.8 | 8.6 |
| | AREA (PERCENT) | | | | | | | | | | | | | | | | |
| Foliage | 61.9 | 61.5 | 65.2 | 68.6 | 68.4 | 65.6 | 69.0 | 61.9 | 62.5 | 57.3 | 51.0 | 67.2 | 88.6 | 79.6 | 67.7 | 72.6 | 67.4 |
| <1/4 | 20.0 | 23.0 | 23.4 | 26.4 | 21.3 | 20.6 | 22.4 | 25.9 | 25.0 | 35.1 | 37.8 | 24.6 | 9.5 | 18.4 | 25.6 | 22.3 | 23.8 |
| 1/4 - 1/2 | 3.4 | 6.2 | 5.6 | 3.3 | 4.3 | 10.0 | 4.2 | 6.2 | 6.7 | 4.0 | 7.6 | 3.4 | 1.6 | 1.3 | 4.9 | 2.8 | 4.7 |
| 1/2 - 1 | 3.9 | 7.6 | 4.3 | 1.3 | 5.8 | 3.8 | 4.4 | 4.7 | 4.0 | 3.6 | 2.3 | 3.0 | .3 | .7 | 1.7 | 2.2 | 3.4 |
| 1 - 3 | .8 | 1.7 | 1.5 | .4 | .2 | 0 | 0 | 1.3 | 1.8 | 0 | 1.3 | 1.8 | 0 | 0 | 0 | .1 | .7 |

Table 3–*Distribution of dead fuel in chamise by weight, volume, and area, as a percent of total fuel in each size class*

| Material size (inch) | Shrub number | | | | | | | | | | | | | | | | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | |
| | WEIGHT (PERCENT) | | | | | | | | | | | | | | | | |
| <1/4 | 4.6 | 6.5 | 7.1 | 18.3 | 7.8 | 7.2 | 9.7 | 5.2 | 7.0 | 14.2 | 13.6 | 9.5 | 14.3 | 1.1 | 3.5 | 8.1 | 8.6 |
| 1/4 - 1/2 | 4.0 | 8.5 | 9.3 | 7.5 | 9.3 | 15.7 | 9.7 | 11.0 | 12.2 | 10.0 | 12.2 | 4.2 | 12.1 | 1.9 | 6.2 | 9.7 | 9.0 |
| 1/2 - 1 | 4.2 | 13.8 | 6.9 | 2.5 | 10.1 | 2.9 | 6.6 | 14.5 | 7.6 | 0 | 3.3 | 10.4 | 3.6 | 2.1 | 0 | 0 | 5.1 |
| 1 - 3 | 1.8 | 8.9 | 1.7 | 4.3 | 0 | 0 | 0 | 4.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | [1]2.1 |
| Total | 14.6 | 37.7 | 25.0 | 32.6 | 27.2 | 25.8 | 26.0 | 34.9 | 26.8 | 24.2 | 29.1 | 24.1 | 30.0 | 5.1 | 9.7 | 17.8 | 24.4 |
| | VOLUME (PERCENT) | | | | | | | | | | | | | | | | |
| <1/4 | 4.0 | 6.1 | 6.4 | 15.4 | 6.8 | 6.2 | 8.2 | 4.8 | 6.5 | 12.4 | 12.6 | 8.5 | 9.9 | 0.8 | 2.9 | 6.6 | 7.0 |
| 1/4 - 1/2 | 3.4 | 7.9 | 8.3 | 6.2 | 8.1 | 13.3 | 8.2 | 10.0 | 11.1 | 9.0 | 11.1 | 3.8 | 8.3 | 1.4 | 5.2 | 7.9 | 7.7 |
| 1/2 - 1 | 3.5 | 2.4 | 6.0 | 2.0 | 8.5 | 2.4 | 5.4 | 12.8 | 6.7 | 0 | 3.0 | 9.0 | 2.4 | 1.4 | 0 | 0 | 4.1 |
| 1 - 3 | 1.5 | 7.9 | 1.5 | 3.4 | 0 | 0 | 0 | 3.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | [1]1.8 |
| Total | 12.4 | 24.3 | 22.2 | 27.0 | 23.4 | 21.9 | 21.8 | 31.3 | 24.3 | 21.4 | 26.7 | 21.3 | 20.6 | 3.6 | 8.1 | 14.5 | 20.3 |
| | AREA (PERCENT) | | | | | | | | | | | | | | | | |
| <1/4 | 4.2 | 7.2 | 6.4 | 12.4 | 7.7 | 7.8 | 8.8 | 6.8 | 8.4 | 14.5 | 19.4 | 10.5 | 4.1 | .4 | 2.0 | 5.3 | 7.9 |
| 1/4 - 1/2 | .9 | 2.5 | 2.4 | 1.0 | 2.1 | 5.4 | 2.0 | 3.1 | 3.5 | 2.0 | 3.6 | 1.1 | .8 | .2 | 1.0 | 1.4 | 2.1 |
| 1/2 - 1 | .5 | 2.8 | 1.0 | .2 | 1.4 | .3 | .7 | 1.9 | 1.2 | 0 | .4 | 1.1 | .1 | .1 | 0 | 0 | .7 |
| 1 - 3 | .2 | .8 | .1 | .2 | 0 | 0 | 0 | .4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | [1] .2 |
| Total | 5.8 | 13.3 | 9.9 | 13.8 | 11.2 | 13.5 | 11.5 | 12.2 | 13.1 | 16.5 | 23.4 | 12.7 | 5.0 | .7 | 3.0 | 6.7 | 10.8 |

[1]Based on shrubs with any material in this size class.

weather conditions the dead fuels can become dry enough to burn readily. The burning dead fuel can provide the heat necessary to dry the living fuel to a point where it will ignite and add to the total energy release from a fire. The amount and distribution of dead fuel in a fuel array can thus greatly affect its flammability.

In the chamise shrubs analyzed, the weights, volumes, and surface areas of the dead woody fuels were tabulated by size classes *(table 3)*. However, there was so little dead foliage that no attempt was made to separate it from the live foliage.

The weight of dead fuel for the 16 shrubs averaged 24.4 percent, which was close to the value found for most of the shrubs. Except for shrubs 14 and 15, which were probably young plants, there was no significant tendency for the amount of dead fuel to vary with the size of the shrub. The distribution of dead fuel volume and surface area followed the same pattern as that for weight, as might be expected. The low average percentage of surface area in dead fuel (10.8 percent) is a reflection of the large proportion of total surface area that is in the foliage *(table 3)*.

The dead material tended to fall in the smaller size classes rather than the large *(table 4)*. On the average more than one-third of the weight of the two smallest classes was made up of dead material, but for some individual shrubs, more than half the weight was dead material. The distribution pattern for the volume and area was similar to that for fuel weight. Chamise shrubs thus have a high proportion of their dead fuel in the easily ignited and fast-burning size classes.

## Fuel Loading

Other conditions being equal, the amount of heat produced by a burning fuel bed will be strongly influenced by the amount of fuel available to burn. Fuel loading (weight per unit of fuel bed area) was determined by assuming each shrub occupied a ground area equivalent to a circle with the diameter of the average crown diameter. Average fuel loading

Table 4–*Proportion of dead fuel in each size class, by weight, volume, and area*

| Material size (inch) | Shrub number | | | | | | | | | | | | | | | | Av |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | |
| | WEIGHT (PERCENT) | | | | | | | | | | | | | | | | |
| <1/4 | 23.4 | 39.5 | 36.8 | 55.7 | 34.7 | 35.4 | 40.8 | 28.3 | 35.6 | 43.5 | 45.2 | 40.4 | 45.9 | 2.8 | 10.3 | 25.2 | 3 |
| 1/4 - 1/2 | 24.7 | 45.9 | 42.9 | 30.2 | 53.1 | 43.8 | 48.4 | 48.7 | 54.0 | 50.4 | 45.2 | 31.2 | 52.0 | 13.9 | 22.0 | 50.6 | 4 |
| 1/2 - 1 | 11.8 | 33.1 | 22.6 | 14.7 | 21.5 | 9.0 | 15.2 | 41.1 | 26.9 | 0 | 17.7 | 41.5 | 39.3 | 13.9 | 0 | 0 | 1 |
| 1 - 3 | 11.4 | 50.5 | 8.8 | 41.9 | 0 | 0 | 0 | 24.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Total[1] | 14.6 | 37.7 | 25.0 | 32.6 | 27.2 | 25.8 | 25.8 | 34.9 | 26.8 | 24.2 | 29.1 | 24.1 | 30.0 | 5.1 | 9.7 | 17.8 | 2 |
| | VOLUME (PERCENT) | | | | | | | | | | | | | | | | |
| <1/4 | 22.2 | 37.8 | 35.2 | 54.0 | 33.1 | 33.8 | 39.0 | 26.9 | 34.0 | 41.0 | 43.5 | 38.7 | 44.2 | 2.6 | 9.7 | 23.9 | 3 |
| 1/4 - 1/2 | 23.8 | 44.6 | 41.6 | 29.1 | 51.7 | 42.5 | 47.1 | 47.4 | 52.7 | 49.1 | 43.8 | 30.1 | 50.6 | 13.3 | 21.1 | 49.3 | 3 |
| 1/2 - 1 | 11.3 | 32.0 | 21.8 | 14.0 | 20.6 | 8.6 | 14.5 | 40.0 | 25.9 | 0 | 17.0 | 40.3 | 38.0 | 12.7 | 0 | 0 | 1 |
| 1 - 3 | 11.0 | 49.6 | 8.5 | 41.0 | 0 | 0 | 0 | 23.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Total[1] | 12.4 | 24.3 | 22.2 | 27.0 | 23.4 | 21.9 | 21.8 | 31.3 | 24.3 | 21.4 | 26.7 | 21.3 | 20.6 | 3.6 | 8.1 | 14.5 | 2 |
| | AREA (PERCENT) | | | | | | | | | | | | | | | | |
| <1/4 | 21.2 | 31.3 | 27.5 | 47.1 | 36.2 | 37.2 | 39.2 | 26.5 | 33.7 | 41.4 | 51.3 | 42.7 | 43.0 | 2.3 | 7.7 | 23.6 | 3 |
| 1/4 - 1/2 | 26.5 | 40.2 | 43.4 | 30.6 | 48.4 | 54.6 | 47.5 | 49.7 | 53.0 | 49.7 | 47.1 | 31.5 | 49.7 | 12.5 | 20.2 | 50.4 | 4 |
| 1/2 - 1 | 12.0 | 37.4 | 22.6 | 15.3 | 25.1 | 6.6 | 16.5 | 39.7 | 30.9 | 0 | 19.3 | 38.3 | 38.1 | 13.4 | 0 | 0 | 1 |
| 1 - 3 | 21.2 | 47.9 | 5.4 | 39.9 | 0 | 0 | 0 | 26.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Total[1] | 5.8 | 13.3 | 9.9 | 13.8 | 11.2 | 13.5 | 11.5 | 12.2 | 13.1 | 16.5 | 23.4 | 12.7 | 5.0 | 1.0 | 3.0 | 6.7 | |

[1]Percent of all fuel.

for the 16 shrubs was 0.45 lb./sq. ft. (equivalent to about 10 tons per acre). There was wide variation in the fuel loading between shrubs:

| Shrub number | Fuel loading *Lb./sq.ft.* | Shrub number | Fuel loading *Lb./sq.ft.* |
|---|---|---|---|
| 1 | 0.72 | 9 | .28 |
| 2 | .55 | 10 | .18 |
| 3 | 1.12 | 11 | .29 |
| 4 | .51 | 12 | .80 |
| 5 | .30 | 13 | .38 |
| 6 | .37 | 14 | .43 |
| 7 | .44 | 15 | .29 |
| 8 | .25 | 16 | .33 |
| | | Average | .45 |

## Fuel Density

Fuel density (weight per unit volume of the fuel) is an important characteristic. Fons (1946) found that rate of spread in small experimental fires decreased as the fuel density increased. Fons, *et al.* (1960) also found this same effect for laboratory crib fires burning rectangular sticks of white fir. The density of wildland fuels can have a wide variation among species.

The density of woody material in chamise was found to vary with the size of material and its condition (alive or dead), but over a relatively narrow range *(fig. 4)*. We have seen that the distribution of weight and volume of the woody material by size classes varied considerably among shrubs *(table 2)*. However, the average density of the woody material by shrubs did not show much variation, probably because the shrubs with a larger amount of large material also tended to have a relatively larger proportion of smaller material. The average density for all shrubs was 46.7 lbs./cu. ft. However, because of the large difference in density between foliage and wood, and the wide variation in the amount of foliage among shrubs, the average density of fuel can be expected to vary greatly among shrubs.

## Surface-to-Volume Ratio

The ratio, $\sigma$, of the fuel surface area to the fuel volume strongly influences flammability. For dead fuels, the moisture that is gained or lost must all go through the surface, so that the rate at which a fuel changes in moisture content is affected greatly by the amount of surface area in relation to the fuel volume. In combustion $\sigma$ is also of major importance. If an unburned piece of fuel is put into a fire, heat is transferred to the fuel surface by all three methods of heat transfer—radiation, convection, and conduction. But the heat received by the surface is transferred to the interior of the fuel by conduction, and it all must go through the surface. Thus, the greater the surface area in relation to the fuel volume, the faster the fuel will be heated and burn.

For cylindrical fuels, $\sigma$ (sq. ft./cu. ft.) can be determined from the equation:

$$\sigma = 2/r$$

in which r = fuel radius in feet.

Fons (1946) found that the rate of fire spread increased linearly with increase in $\sigma$ for small experimental fires over a range of from 1.3 to 12 sq. ft./cu. ft. Fons, *et al.* (1960) also found rate of spread to be directly proportional to $\sigma$ for small crib fires of rectangular sticks.

Fons (1950), in investigating the effect of various fuel factors on ignition time with a muffle furnace, found that ignition time decreased with decreasing fuel size (increasing $\sigma$) over a range of furnace temperatures of 850° to 1,300°F. However, his data indicated fuel size had less effect on ignition time as the furnace temperature was increased.

The variation in $\sigma$ is pronounced. Fuel one-eighth inch in diameter has a $\sigma$ of 384, whereas for one-inch diameter fuel, $\sigma$ is only 48. There is little information on $\sigma$ values for most wildland fuels. Rothermel and Anderson (1960) obtained $\sigma$ values of 2,700 sq. ft./cu. ft. and 1,741 sq. ft./cu. ft. for white pine and ponderosa pine needles respectively. Cheat grass has a

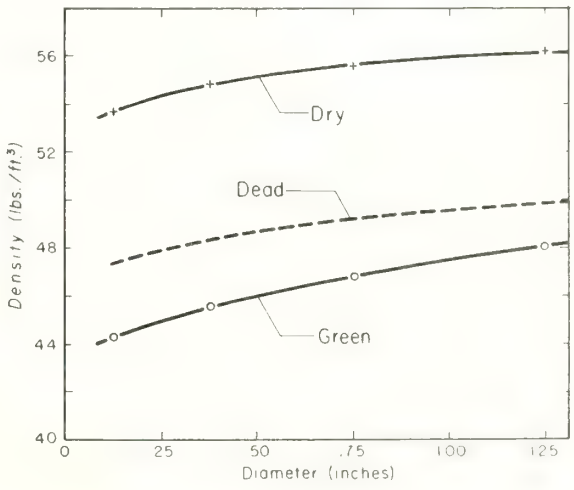


Figure 4 *Density of chamise wood varies with the size of material and its condition (alive or dead).*

$\sigma$ in the order of 4,390 sq. ft./cu. ft.[1] Spruce-Douglas-fir slash fuels in the northern Rocky Mountain area have been estimated to have values ranging from 305 sq. ft./cu. ft. to 2,134 sq. ft./ cu. ft.

Average surface-to-volume ratio for the shrubs was 690 reflecting the predominance of very small fuel:

| Shrub number | $\sigma$ | Shrub number | $\sigma$ |
|---|---|---|---|
| | *Sq. ft./cu. ft.* | | *Sq. ft./cu. ft.* |
| 1 | 581 | 9 | 444 |
| 2 | 385 | 10 | 668 |
| 3 | 459 | 11 | 522 |
| 4 | 815 | 12 | 581 |
| 5 | 560 | 13 | 1,334 |
| 6 | 618 | 14 | 1,228 |
| 7 | 718 | 15 | 758 |
| 8 | 490 | 16 | 887 |
| | | Average | 690 |

## Fuel Bed Porosity

The spacing of individual fuel elements in the fuel bed, or how crowded they are together may be referred to in terms of porosity, or its converse, compactness. In a highly compact fuel bed the fuel elements are closely packed together, whereas in a less compact fuel bed the individual fuel elements are spaced far apart. A highly compact fuel bed has a low porosity value and a less compact bed is more porous.

Fuel bed compactness or porosity can be expressed in several ways. Fons (1946) used the ratio ($\lambda$) of the volume of voids in the fuel bed to the surface area of the fuel to measure porosity. He correlated rate of spread of small experimental fires with the reciprocal of this ratio (compactness). His work showed that rate of spread increased rapidly with decreasing compactness (increasing porosity).

Rothermel and Anderson (1966) correlated rate of spread of small laboratory fires with the product of $\sigma$ and $\lambda$. They found the spread rate increased rapidly as this product increased. By definition, the product of $\sigma$ and $\lambda$ is the ratio of fuel bed void volume to fuel volume—another means of expressing fuel bed porosity. However, in the data used in the correlation, $\sigma$ as well as $\lambda$ varied. Since rate of spread varies with both parameters, it is not clear from their published work how much of the change in spread rate was due to the surface-to-volume ratio of the fuel and how much to fuel bed porosity.

There seems to be little information on the effect of fuel bed porosity on burning rate of wildland fuels. One would expect the burning rate to be slow for fuel beds with low porosity since air flow into the fuel bed would be restricted and the oxygen supply deficient. The burning rate should increase rapidly as the porosity is increased and reach a maximum at some optimum fuel element spacing. Beyond this point, further increases in porosity should lead to a decreasing burning rate because of a reduction in the efficiency of heat transfer among the fuel elements as they become further and further apart.

A convenient way to express fuel bed compactness is by the packing ratio ($\beta$). This is defined as the ratio of fuel volume to fuel bed volume. The reciprocal ($\gamma$) of this ratio is the fuel bed porosity. Packing ratios and fuel bed porosities were determined for each of the shrubs analyzed in this study. Fuel bed volume was obtained by assuming the shrub occupied a cylinder having the height of the shrub and a diameter equal to the average crown diameter. Packing ratios calculated in this manner showed a wide variation, ranging from a low of 0.00068 to a high of 0.00374:

| Shrub number | $\beta$ | $\gamma$ |
|---|---|---|
| 1 | 0.00291 | 344 |
| 2 | .00214 | 467 |
| 3 | .00327 | 305 |
| 4 | .00310 | 323 |
| 5 | .00112 | 893 |
| 6 | .00179 | 558 |
| 7 | .00153 | 653 |
| 8 | .00068 | 1,471 |
| 9 | .00087 | 1,149 |
| 10 | .00092 | 1,087 |
| 11 | .00148 | 676 |
| 12 | .00297 | 337 |
| 13 | .00343 | 292 |
| 14 | .00422 | 237 |
| 15 | .00243 | 412 |
| 16 | .00133 | 752 |

There are few data on the packing ratios for natural wildland fuels. Ponderosa pine needle fuel beds may have a packing ratio of about 0.06250, whereas standing cheat grass has a packing ratio in the order of 0.00004. The relatively high porosity values for chamise indicate that very little of the fuel bed volume is occupied by fuel. For fuel bed with a packing ratio of 0.00068, less than 0.07 percent of the fuel bed volume is occupied by fuel, and for a packing ratio of 0.00374 only about 0.37 percent.

Much of the material of a chamise shrub is small sized, as we have seen; these fuels contribute most to the energy peak that exerts a major control on fire behavior (Countryman 1969). The larger-sized fuel

[1]Brown, J. K. *Physical fuel properties and their vertical variation in spruce-fir logging slash.* (MS in preparation)

elements can be considered simply as a supporting framework for the small fuels. This framework permits a fuel element distribution conducive to a high fuel bed porosity and rapid burning. The fuel distribution pattern and high porosity of chamise is shown in *figure 5*.

## Fuel Moisture Content

The moisture content of wildland fuel has long been recognized as having a major influence on the ignition, development, and spread of fires (Hawley 1926). Studies have been made of moisture content

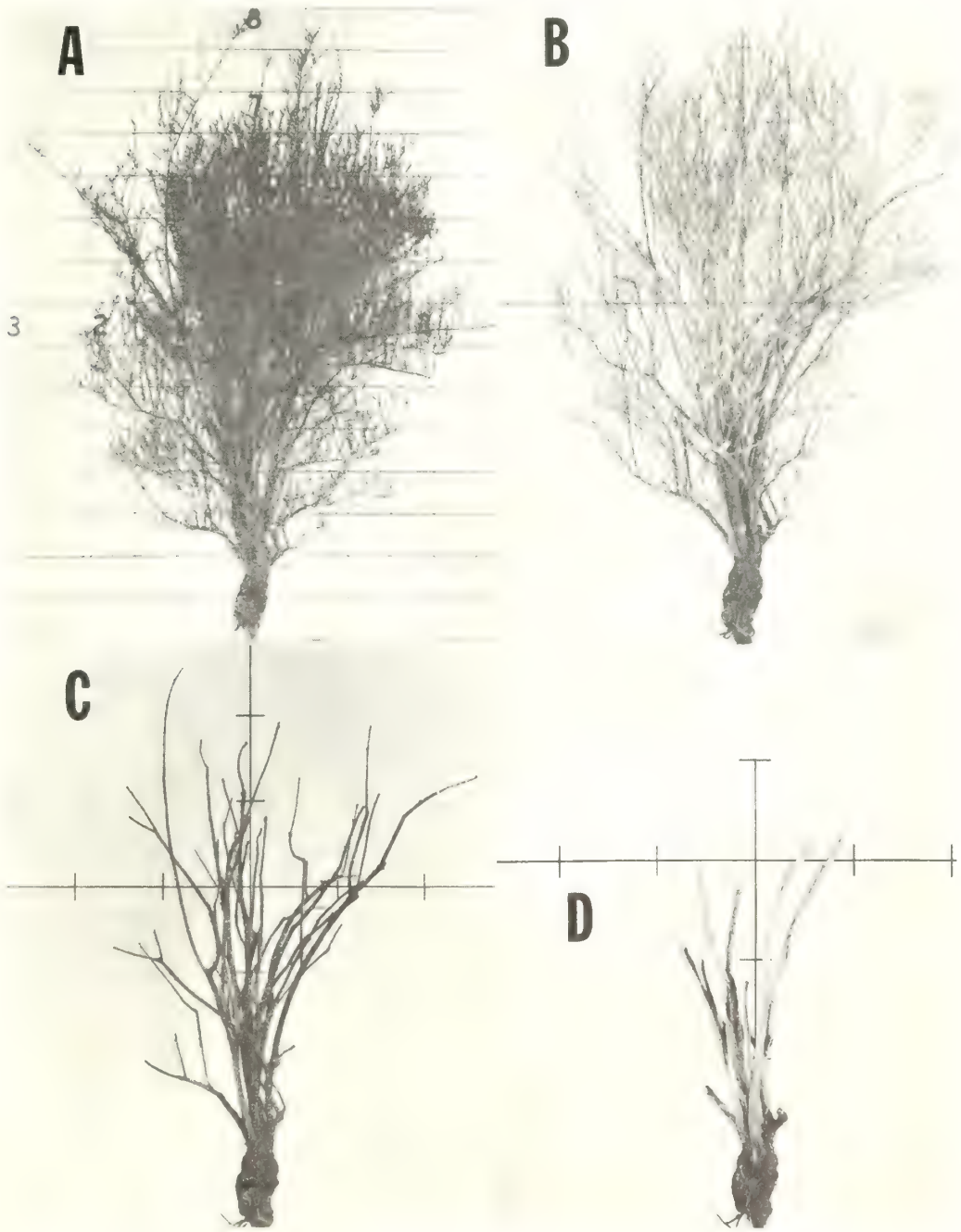


Figure 5—*Distribution of chamise fuel:* A, *Chamise shrub with foliage;* B, *Foliage removed;* C, *Material ¼ inch and less removed; and* D, *Material ½ inch and less removed.*

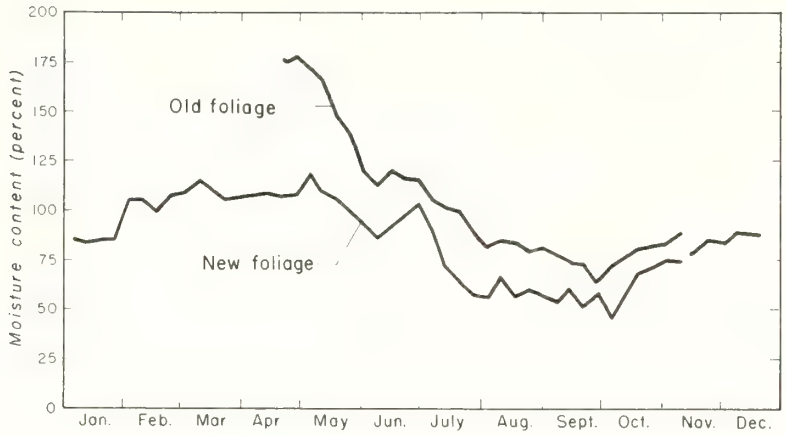


Figure 6—*A typical moisture-time history for chamise foliage shows rise and decline in moisture content.*

variations (e.g., Fielding 1952; Firestop 1955; Olsen 1960; Philpot 1963). Studies have also been made on the effect of fuel moisture on fire behavior (e.g., Curry and Fons 1938; Fons 1946; Fons 1950; Rothermel and Anderson 1966).

The moisture content of dead chamise is directly dependent on atmospheric moisture, since dead fuels are hygroscopic. Because much of the dead fuel in chamise is small and the fuel bed is very porous, the moisture content of the dead fuel can be expected to respond very quickly to changes in relative humidity and temperature. Since the dead fuel effects the way chamise burns, the behavior of fire in chamise can also be expected to change quickly with variations in temperature and humidity. Observations of wild fires in chamise tend to bear this out.

The moisture content of the living chamise fuel depends largely on the physiological activity of the plant. During the late fall and winter months when the shrubs are dormant, the moisture content remains relatively constant, typically between 80 and 110 percent of the dry weight. As the spring growing season approaches, the moisture content of the mature foliage and fine material rises slowly. The new growth, usually reaching its maximum development between March and May, has a very high moisture content—sometimes over 200 percent. The moisture content of both the mature and new growth decline during the summer and reach a minimum in September or October. A typical moisture-time history for mature and new growth foliage[2] is shown in *figure 6.*

[2]Fons, Wallace L. *Progress report on seasonal variation of moisture content of chaparral foliage on the San Dimas Experimental Forest during 1942.* (Unpublished rep. on file at Forest Fire Laboratory, Pacific SW. Forest & Range Exp. Sta., Riverside, Calif.)

Since the new growth has a high moisture content relative to the mature growth, the amount of new growth present has an important bearing on the average moisture content of the fuel complex, and hence on the way it burns. The amount of new growth varies widely from year to year, dependent upon the amount of winter and spring precipitation and other weather conditions. In some years practically no new growth appears; in others new growth may make up an estimated 15 to 20 percent of fine living material.

## Heat Content

The characteristics of a wildland fire depend, in part, upon the heat that is available in the fuel. Heat content values for most wildland fuels fall within a range of 7,500 to 10,000 B.t.u./lb. For six of the shrubs used in this study the heating value was determined by using standard bomb calorimetry methods (American Society for Testing Materials 1966). The foliage and less than ¼-inch size class had nearly identical average heat values. The other size classes had values that were similar to each other, but about 600 B.t.u./lb. lower *(table 5).* This difference is probably due to a variance in chemical composition between foliage and small twigs and the larger woody material.

## Chemical Composition

The effect of chemical composition of wildland fuels on fire characteristics has only recently received attention. The two important classes of chemicals are (a) the high-energy ether extractives (waxes, oils, terpenes, and fats) and (b) the minerals which affect the pyrolysis of carbohydrates. Mutch (1964) found the ignition time for ponderosa pine powder to be

Table 5 – *Heat content of chamise, by size of material*

| Shrub number | Foliage | Material (inch) . . . | | |
|---|---|---|---|---|
| | | <1/4 | 1/4 - 1/2 | 1/2- 1 |
| | *B.t.u./lb.* | | | |
| 6 | 8,983 | 9,085 | 8,436 | 8,360 |
| 7 | 8,570 | 8,779 | 7,869 | 8,449 |
| 10 | 8,938 | 8,783 | 8,344 | 8,156 |
| 14 | 9,341 | 9,072 | 8,297 | 8,320 |
| 15 | 8,964 | 9,144 | 8,665 | 8,585 |
| 16 | 9,014 | 9,106 | 8,352 | 8,486 |
| Average | 8,968 | 8,995 | 8,327 | 8,393 |

much longer than for sphagnum moss powder. The pine had over four times more extractives than the moss. However, pilot ignition time for both fuels was increased by the removal of the extractives. Recently, Philpot (1969a) found that the burning rate of aspen leaves was reduced by solvent extraction. Philpot and Mutch (1968) found a similar relationship for guava leaves treated with herbicides, which had extractive contents different from those of the controls.

Broido and Nelson (1964) attribute the difference between burning of naturally leached and unleached corn plants to ash and phosphorus content. The leached plants contained 3.7 percent ash and 0.17 percent phosphorus. The ash and phosphorus of nonleached plants was 11.4 percent and 0.53 percent. The leached plants burned readily, but the non-leached would not sustain flaming. Philpot (1968) found a direct relationship between pyrolysis rate, volatile production, and other thermal characteristics and the effective mineral contents of several species of plant material.

We determined the ash, potassium, and phosphorus content of chamise from samples of different sized materials. All of these chemical components decreased as the size of material increased *(table 6)*.

The ether extractives generally have a much higher heat value than other wood constituents. Thus, if they are present in sizeable amounts they can significantly affect the heat value of a fuel.

Philpot (1969a) analyzed samples from the shrubs used in this study along with additional samples from the same area. He found that ether extractives from the foliage varied from about 8 percent to nearly 12 percent of the foliage weight. The amount of extractives in the woody material was less–ranging from 3.4 percent to 8.8 percent. Heat values for the extracted materials as high as 17,378 B.t.u./lb. for the foliage and 24,533 B.t.u./lb. for the woody material were found. These heat values are very much higher than for the plant parts as a whole *(table 5)*.

Table 6–*Variation in chemical components of chamise, by size classes*

| Item | Foliage | Material (inch) . . . | | |
|---|---|---|---|---|
| | | <1/4 | 1/4 - 1/2 | 1/2 - 1 |
| | *Percent* | | | |
| Ash | 4.31 | 2.47 | 2.09 | 1.76 |
| Potassium | .39 | .22 | .17 | .16 |
| Phosphorus | .089 | .078 | .047 | .042 |

# ESTIMATING PHYSICAL CHARACTERISTICS

Reliable estimates of the physical characteristics of fuels can be derived from direct measurements and analyses of fuel taken from small areal plots. But estimates obtained in this way are time consuming–and time is not available when the information is needed immediately, as for control operations on a going fire. Then means of obtaining approximations of the fuel characteristics quickly are much needed.

Some techniques for estimating the physical characteristics of chamise have been worked out, and will be described here. It must be kept in mind, however, that the data given here were drawn from the shrubs analyzed in this study.

## *Fuel Surface Area*

The surface area of a natural fuel is perhaps the most difficult of the fuel parameters to measure or estimate. As previously described, in this study the woody material as well as the foliage was assumed to have a smooth-surfaced geometrical shape from which the area was calculated. However, the surface of wildland fuels is seldom smooth, but is usually fissured and has numerous protuberances. Also different fuel particles vary considerably in conformation. Therefore the assumption tends to result in under-estimation of the actual surface area. Hence the

fuel surface area determined for chamise must be considered only an approximation of the actual area.

A large part of the fuel surface area in chamise was found to be in the smaller fuel size classes–most of it in the foliage. Since the foliage grows chiefly on the small twigs, the amount of material in the smallest size class also tended to increase with increasing amounts of foliage. For these reasons the surface area (sq. ft.) per pound of fuel, $A_f$, was correlated with the proportion of the shrub in foliage to provide a means for estimating the fuel surface area. This gave a prediction equation of the form:

$$A_f = 64.96\ P_f^{.8945}$$

in which $P_f$ is the proportion of the shrub volume in foliage *(fig. 7)*.

Use of either the curve or equation permits an approximation of the total fuel surface area from the proportion of foliage and the fuel loading. The surface-to-volume ratio can then be calculated from the equation:

$$\sigma = A_f d$$

in which d is the average density of the shrub.

## Fuel Loading, Packing Ratio, Density

Estimation of any one of these parameters is possible if the others are known, along with the fuel bed height. As we have seen, fuel loading ($W_a$) is the fuel weight per unit of fuel bed area; fuel density (d) is the weight of a unit volume of fuel, and the packing ratio ($\beta$) is the volume of fuel per unit volume of fuel bed. These definitions can be expressed algebraically as follows:

$$W_a = W/A$$
$$d = W/V_f$$
$$\beta = V_f/V_b$$

in which A = fuel bed area, $V_f$ = fuel volume, $V_b$ = fuel bed volume, and W = fuel weight.

Fuel loading is dependent upon both fuel density and the packing ratio. If we divide fuel loading ($W_a$) by the fuel bed height (h), then we can write the equation:

$$W_a/h = d\beta$$

or more simply

$$W_a = hd\beta.$$

Thus, if any three of these fuel parameters are known, the fourth can be calculated. Fuel bed height can generally be obtained with little difficulty by direct field measurement. The other parameters are more difficult to measure directly, and sampling, estimating, or some other means of approximation are usually necessary.

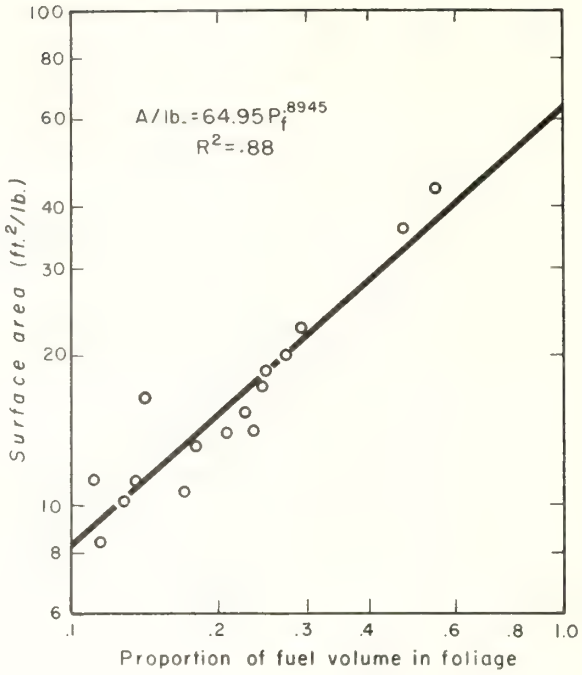


Figure 7—*Total fuel surface area of chamise is correlated with proportion of the shrub in foliage.*

The chief causes of variation in the average density of the fuel material in chamise were found to be the relative amount of dead material and the proportion of the shrub in foliage. Average fuel densities for the different proportions of these fuel components have been calculated *(table 7)*. Estimates may be made from the table for the variations likely to be encountered.

To obtain the packing ratio, we must know the fuel loading and fuel density, or the fuel volume. Since it is impractical to measure either fuel weight or fuel volume on a full-scale basis, sampling is necessary. The samples may be individual shrubs as in the present study, or plots of known area.

Where an estimate of the packing ratio or fuel loading is needed immediately, as for fire behavior prediction on a going fire, the sampling procedure is not feasible. Skill in visually estimating fuel loading can be developed with practice and observation of fuel beds of known loading, and this method of estimating fuel loading is frequently used. From such estimates, the fuel density, and the fuel bed height, calculations of the packing ratio is then possible.

For the 16 shrubs analyzed, the packing ratio

Table 7—*Average fuel density for chamise, by percent of volume dead*

| Percent foliage (vol.) | Percent dead (volume) . . . | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | [1]100 |
| | *Lb./cublic ft.* | | | | | | | | | | |
| 0 | 46.0 | 46.2 | 46.5 | 46.8 | 47.0 | 47.2 | 47.5 | 47.8 | 48.0 | 48.2 | 48.5 |
| 10 | 43.6 | 43.8 | 44.0 | 44.3 | 44.5 | 44.7 | 45.0 | 45.2 | 45.4 | 45.6 | 46.0 |
| 20 | 41.2 | 41.4 | 41.6 | 41.8 | 42.0 | 42.2 | 42.4 | 42.6 | 42.8 | 43.0 | 43.4 |
| 30 | 38.8 | 38.9 | 39.2 | 39.4 | 39.5 | 39.6 | 39.8 | 40.1 | 40.2 | 40.3 | 40.9 |
| 40 | 36.4 | 36.5 | 36.7 | 36.9 | 37.0 | 37.1 | 37.3 | 37.5 | 37.6 | 37.7 | 38.4 |
| 50 | 34.0 | 34.1 | 34.2 | 34.4 | 34.5 | 34.6 | 34.8 | 34.9 | 35.0 | 35.1 | 35.9 |
| 60 | 31.6 | 31.7 | 31.8 | 31.9 | 32.0 | 32.1 | 32.1 | 32.3 | 32.4 | 32.5 | 33.3 |
| 70 | 29.2 | 29.3 | 29.4 | 29.4 | 29.5 | 29.6 | 29.6 | 29.7 | 29.8 | 29.9 | 30.8 |

[1]Foliage density adjusted to dry volume.

varied widely, ranging from 0.00422 to 0.00068. Differences in packing ratios among the shrubs were visually apparent, suggesting that ocular estimates of the packing ratio might be practical. If the packing ratio can be estimated, then fuel loading can be calculated.

Techniques for estimating the packing ratio have not been developed or tested. Photographs of chamise of known packing ratios would aid the estimator in determining appropriate values. Whether estimates of packing ratios or fuel loading would produce the most accurate result also is not known. However, since fire behavior is sensitive to both fuel loading and packing ratio, both parameters are essential to fire behavior prediction and evaluation and must be obtained in some way.

## Critical Fuels

Earlier it was indicated that in most chaparral fires only the fuel less than one-half inch in diameter usually burns. Estimates of the characteristics of these "critical" fuels are thus likely to be of more importance for many purposes than is the total amount of fuel. To obtain the loading of critical fuels, the same equation may be used as for total fuel loading. However, both the average fuel element density (d) and the packing ratio ($\beta$) will be different. In the study, average fuel densities for different proportions of dead material and foliage were calculated in the same manner as for the total fuel, except that only woody material one-half inch or less in diameter was included in the calculations *(table 8)*.

Packing ratios for the fuel up to one-half inch in diameter (including foliage) were also determined. In making visual estimates of packing ratios, the estimator will probably be influenced strongly by the critical fuels. Most of the foliage and fine material in chamise is on the exterior of the shrub and it is this fuel that gives the shrub the appearance of being dense or sparse. Thus visual estimates of packing

Table 8—*Average fuel density for critical fuel in chamise, by percent of volume dead*

| Percent foliage (vol.) | Percent dead (volume) . . . | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | [1]100 |
| | *Lb./cubic ft.* | | | | | | | | | | |
| 0 | 44.0 | 45.2 | 45.5 | 45.9 | 46.2 | 46.5 | 46.8 | 47.1 | 47.5 | 47.8 | 48.1 |
| 10 | 42.6 | 42.9 | 43.2 | 43.5 | 43.8 | 44.0 | 44.3 | 44.6 | 45.0 | 45.2 | 45.6 |
| 20 | 40.3 | 40.6 | 40.8 | 41.1 | 41.4 | 41.6 | 41.8 | 42.1 | 42.4 | 42.6 | 43.1 |
| 30 | 38.0 | 38.2 | 38.4 | 38.7 | 38.9 | 39.2 | 39.4 | 39.6 | 39.9 | 40.1 | 40.6 |
| 40 | 35.7 | 35.9 | 36.1 | 36.3 | 36.5 | 36.7 | 36.9 | 37.1 | 37.3 | 37.5 | 38.1 |
| 50 | 33.4 | 33.6 | 33.8 | 34.0 | 34.1 | 34.2 | 3.44 | 34.6 | 34.8 | 34.9 | 35.6 |
| 60 | 31.2 | 31.3 | 31.4 | 31.6 | 31.7 | 31.8 | 31.9 | 32.0 | 32.2 | 32.3 | 33.2 |
| 70 | 28.9 | 29.0 | 29.0 | 29.2 | 29.3 | 29.4 | 29.4 | 29.5 | 29.7 | 29.7 | 30.7 |

[1]Foliage density adjusted to dry volume.

ratios are likely to be more accurate for the critical fuels than for total fuel for shrubs like chamise. Packing ratios for the critical fuels were considerably smaller than for the total fuel as might be expected:

| Shrub (No.): | Packing ratio | Fuel bed porosity |
|---|---|---|
| 1 | 0.00163 | 613 |
| 2 | .00020 | 1,031 |
| 3 | .00180 | 556 |
| 4 | .00240 | 417 |
| 5 | .00064 | 1,562 |
| 6 | .00129 | 775 |
| 7 | .00097 | 1,031 |
| 8 | .00035 | 2,857 |
| 9 | .00046 | 2,174 |
| 10 | .00058 | 1,724 |
| 11 | .00097 | 1,031 |
| 12 | .00155 | 645 |
| 13 | .00321 | 312 |
| 14 | .00374 | 267 |
| 15 | .00193 | 518 |
| 16 | .00098 | 1,020 |
| Average | .00142 | 1,033 |

Fuel surface area for the critical fuel was correlated with the proportion of the shrub volume in foliage. This gave a curve similar in form to that obtained for the total fuel area *(fig. 8)*. For calculation of the surface-to-volume ratio, the same equation as for total fuel may be used.

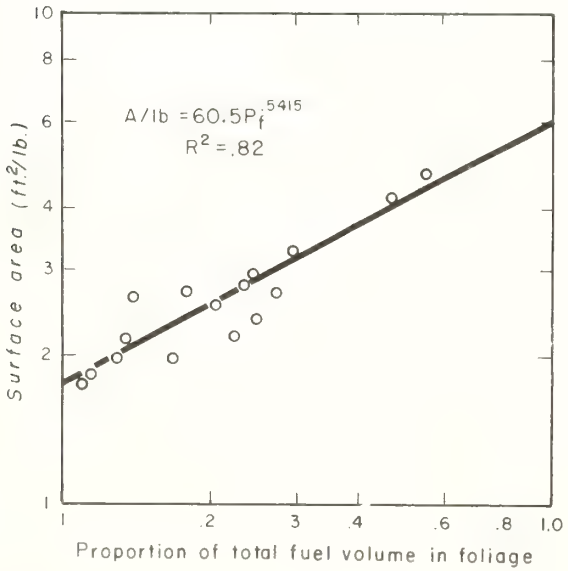


Figure 8—*Surface area of critical fuels in chamise is correlated with the proportion of the shrub volume in foliage.*

The preceding techniques for estimating fuel surface area and fuel loading for both total and critical fuels assume full coverage of the ground area by fuel. If clear spaces exist in the area of interest, then the estimates must be reduced in proportion to the area that is not fuel covered.

## Dead Fuel

The amount of dead fuel in chamise can be expected to vary with the age of the plants and with the environmental stresses to which it has been subjected. In southern California, drought and air pollution have been observed to have a marked effect in killing all or parts of chaparral shrubs. Insects and disease also take their toll.

The chamise stand sampled was essentially even-aged. Although the amount of dead fuel varied considerably, the proportion of dead fuel did not show any strong relationship with other fuel parameters. Thus estimates of the proportion of dead fuel must be made from direct measurements or visual observations.

## Moisture Content

Live and dead fuels occur naturally in a mixture for many of our wildland fuels, and each has a separate pattern of variation. The effect of the moisture content of dead fuels on fire has been studied extensively. But little is known of the effect of moisture content of living fuel, and even less about that of mixtures of live and dead fuel.

Direct fuel-moisture determination is a time-consuming laboratory procedure. Since moisture content can change quickly, particularly in dead fuels, laboratory moisture determinations are not practical for predicting probable fire behavior for an immediate situation, and indirect means are required. For dead fuels moisture content is estimated from observations of relative humidity, temperature, precipitation, etc., or by some analog device such as the fuel moisture sticks used in many danger rating systems. For reliable estimates, the relationships between actual fuel moisture and environmental conditions or the analog device must be known. Unfortunately, these relationships have been determined for only a few wildland fuels, and chamise is not one of these.

Estimation of moisture in living fuels is largely an unsolved problem. For chaparral fuels in California an approximation of moisture content for fire danger rating purposes is obtained through use of the normal seasonal variation curve *(fig. 6)*. The approximation is

crude, however, and not very well suited for fire behavior prediction.

In general, present means of estimating fuel moisture are not satisfactory for evaluating the fire potential for a given fuel situation. Since fuel moisture is known to have a pronounced effect on fire, more precise means of estimating it are badly needed.

## Chemical Composition

Although chemical composition is very difficult to estimate, this fuel characteristic cannot be neglected. Research has indicated that for chamise, at least, the chemical composition may change significantly during the year.

There is likely to be some variation from place to place, depending upon soil and climatic conditions, but chemical composition and its seasonal variations are probably highly species dependent. The variation between species is likely to be much more important than the variation within a species. Determination of the chemical composition of a fuel requires complicated laboratory procedures, and hence cannot be accomplished in the field. However, once the chemical composition and seasonal variation for a representative sample of a given species are established, this information can usually be applied generally to the species.

## Heat Content

The heat content does not vary much within a given species, and the variation between species is not great for most wildland fuels. The heat content of chamise does vary with the season of the year as a result of the change in chemical composition. If this effect is found to be important, then it must be included in evaluating the fuel in terms of its fire potential. Like chemical composition, the measurement of heat value is a laboratory procedure. But since areal variations are likely to be small, values found for the species can be applied generally.

It is no revelation that chamise will burn hot and fast. Firefighters have been aware of this for many years. The relatively large amount of small material—much of it dead—loosely arranged in the fuel bed gives chamise a large surface-to-volume ratio and a low packing ratio. These factors are conducive to a rapid rate of energy release. The seasonal pattern of living fuel moisture and amount of ether extractive materials with their high heat content makes chamise most flammable in late fall. Traditionally, in southern California where chamise predominates, the worst fire weather also occurs at the same time. Thus the physical characteristics of chamise and the weather combine to make the reputation of chamise as one of the most hazardous fuels a well deserved one.

## SUMMARY

Predicting fire behavior is highly dependent upon knowledge of fuel characteristics. Chamise *(Adenostoma fasciculatum),* one of the most hazardous wildland fuels in southern California, is well known to burn hot and fast. Why it does so was determined in an analysis of 16 shrubs from the North Mountain Experimental Area, 30 miles east of Riverside, California.

Chamise has physical characteristics that are conducive to a rapid rate of energy release. The relatively large amount of small material—much of it dead—loosely arranged in the fuel bed gives this shrub a large fuel surface area compared to fuel volume, and an openly arranged fuel bed. The seasonal pattern of moisture in living fuel and amount of ether extractives with their high heat content makes chamise most flammable in late fall, when fire weather in southern California becomes the most hazardous.

Reliable estimates of the physical characteristics of fuels can be derived from direct measurements and analyses of fuel taken from sample plots. But estimates obtained in this way are time consuming, and means of approximating fuel characteristic values are needed. Techniques for estimating some of the characteristics of chamise have been worked out.

The fuel surface area for both the total fuel array

Countryman, Clive M., and Charles W. Philpot.
1970. **Physical characteristics of chamise as a wildland fuel.** Berkeley, Calif., Pacific SW. Forest & Range Exp. Sta., 16 p., illus. (USDA Forest Serv. Res. Paper PSW-66)

*Oxford:* 176.1 *Adenostoma fasciculatum:* 431.2.
*Retrieval Terms: Adenostoma fasciculatum;* burning characteristics.

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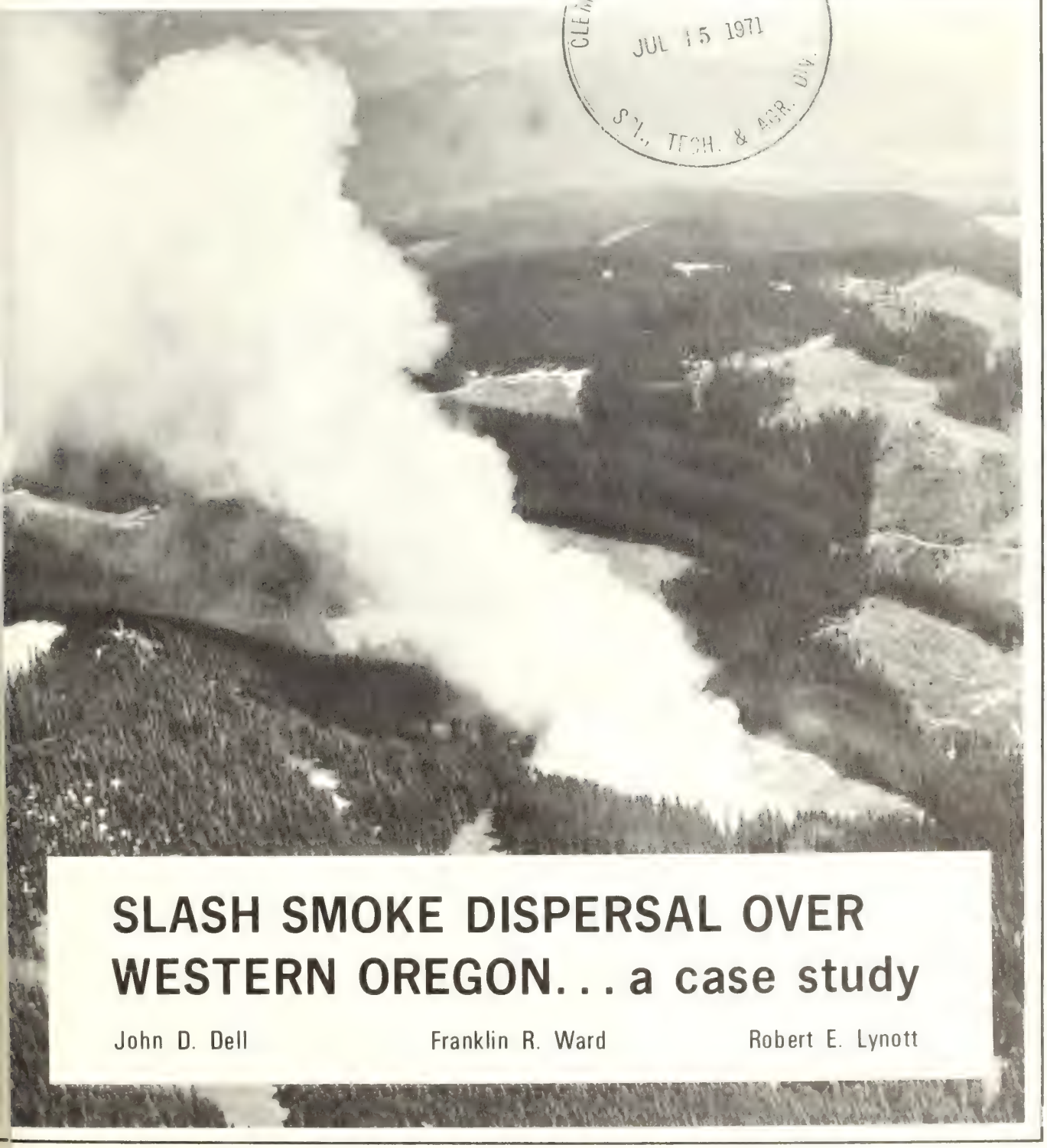

# SLASH SMOKE DISPERSAL OVER WESTERN OREGON... a case study

John D. Dell Franklin R. Ward Robert E. Lynott

USDA FOREST SERVICE RESEARCH PAPER PSW- 67 /1970

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## The Authors

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## ACKNOWLEDGMENT

We gratefully acknowledge the assistance of Robert Y. Lee, fire weather forecaster, U.S. Weather Bureau, Portland, Oregon, in collecting and interpreting weather data.

On October 20, 21, and 22, 1969, more than 350,000 tons of logging slash were burned in the Cascade Mountains above 2,600 feet mean sea level (m.s.l.[1])—yet the fires added almost no smoke to the already seriously contaminated air below that level in the populous Willamette Valley of western Oregon. At times, smoke in the mountains was dense, but winds carried it over the sparsely populated areas east of the Cascades. We reached this conclusion after a study of aerial observations made on the afternoons of October 20 and 22.

Because of national and local concern for air quality control, forest slash burning is being scrutinized critically as a contributor to air pollution in Oregon and Washington. Accumulated slash is potential fuel for the large, destructive conflagration, and presently the most practical treatment is controlled burning. Foresters realize, nevertheless, that indiscriminate burning of debris without regard to location, time, atmospheric conditions, or fuel condition and arrangement can contaminate the air with smoke. They are learning that slash can be eliminated by prescribed burning with a minimal effect on air quality in high population centers.

This paper reports a study to determine if smoke from large-scale slash burning in the Cascade Range contaminated the atmosphere in the Willamette Valley during a 3-day period of stable air conditions. The weather conditions during this episode in October are typical for the autumn slash burning season in western Oregon. A detailed analysis of weather data is a part of the study, which is in effect a case history of burning conditions and smoke dispersal during a representative burning operation.

## WEATHER PATTERNS

An anticyclone, or high pressure area, moved westward over Oregon during the period Saturday, October 18 to Wednesday, October 22 *(fig. 1)*. It was accompanied by strong subsidence, or sinking, of the air mass, which caused marked stability at elevations below 10,000 feet (m.s.l.). The episode was followed by the arrival of cyclonic flow, upward motion, and a transition to an unstable air mass by Thursday, October 23.

At 1600 P.s.t. on Saturday, at 9,300 feet over Salem, in the central Willamette Valley, the temperature had risen to 35°F.—an increase of 15° since 0400 the same day *(fig. 2)*. Wind flow below 5,000 feet became light. The subsidence and warming trend temporarily leveled off Saturday night, owing to the approach of a dissipated storm front, which moved around the northern portion of the High. Also, nighttime cooling occurred below 2,400 feet. By Sunday morning, the air over Salem was virtually isothermal from the surface to 7,500 feet, an example of marked stability *(fig. 2)*.

Even though the High moved inland over Oregon, there were widespread clouds over the northern half of the State, and sprinkles in western Washington. Subsidence was renewed late Sunday night and continued over northwest Oregon for 36 hours *(fig. 2)*. During the entire study period, with few exceptions, the winds were generally westerly *(fig. 3)*.

At 0400 on Tuesday, October 21, an upper air

[1]All elevations used in this report refer to mean sea level unless otherwise noted.

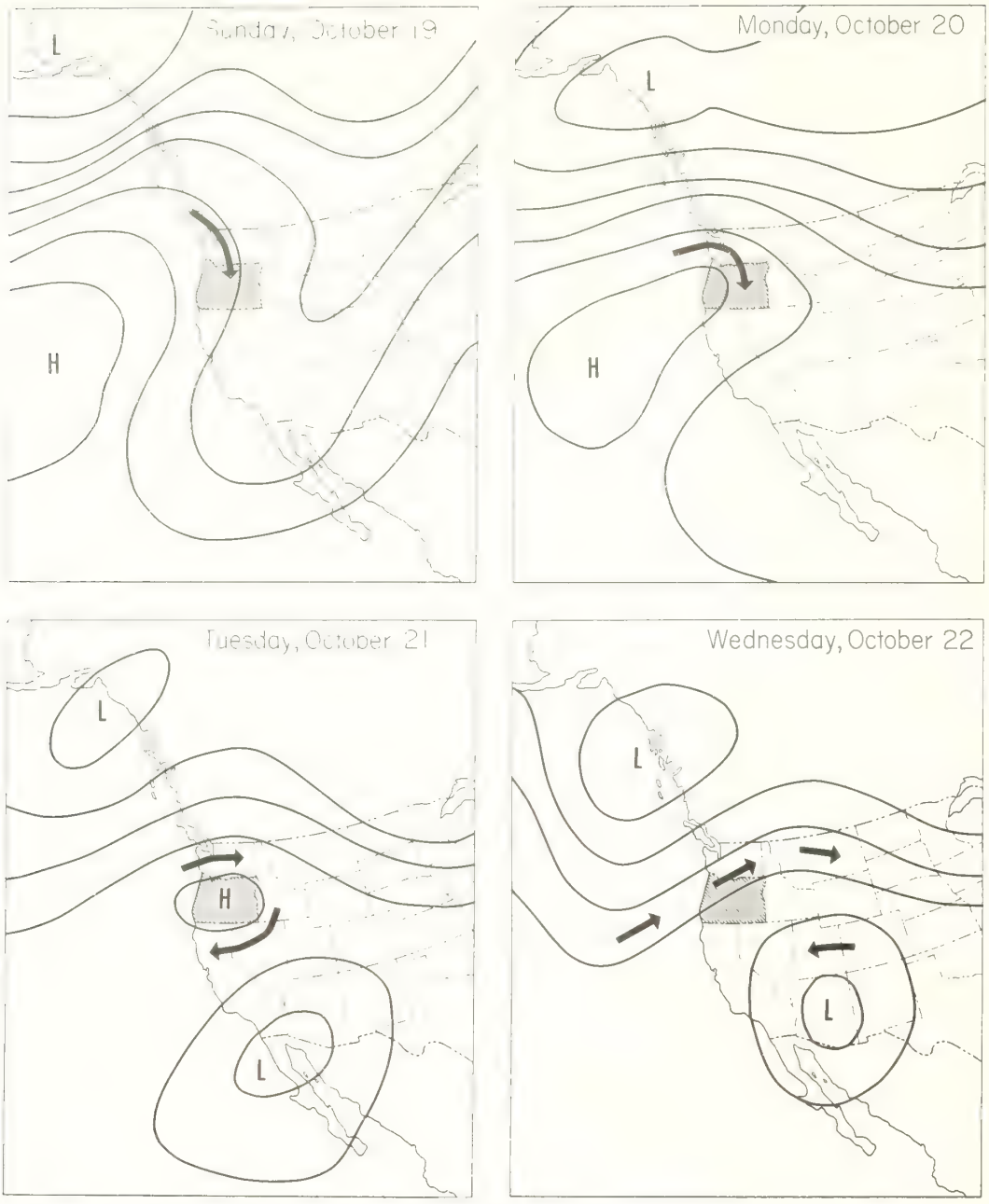


Figure 1—*Wind flow at 10,000 feet (m.s.l.) varied widely on the mornings of the 4 days studied (October 10-22, 1969).*

sounding from Salem showed a temperature of 39°F. at the ground and 65°F. at 2,600 feet—an inversion of 26°. From Sunday morning until Tuesday morning, winds below 5,000 feet in the Willamette Valley averaged less than 5 miles per hour.

By Tuesday afternoon, the center of the anticyclone at 5,000 feet was near Boise, Idaho—but high pressure still dominated northwest Oregon. Warming over Salem reached its climax as moderate southwest winds 12-14 miles per hour *(fig. 3)*, began to develop at 3,000 to 6,000 feet. The air mass above 2,800 feet had become less stable because of the warming at that level, with only negligible warming at the 10,000-foot level during the preceding 48 hours *(fig. 2)*. The air mass below 2,800 feet remained highly stable.

A cooling process began Tuesday night and continued rather steadily during the rest of the period

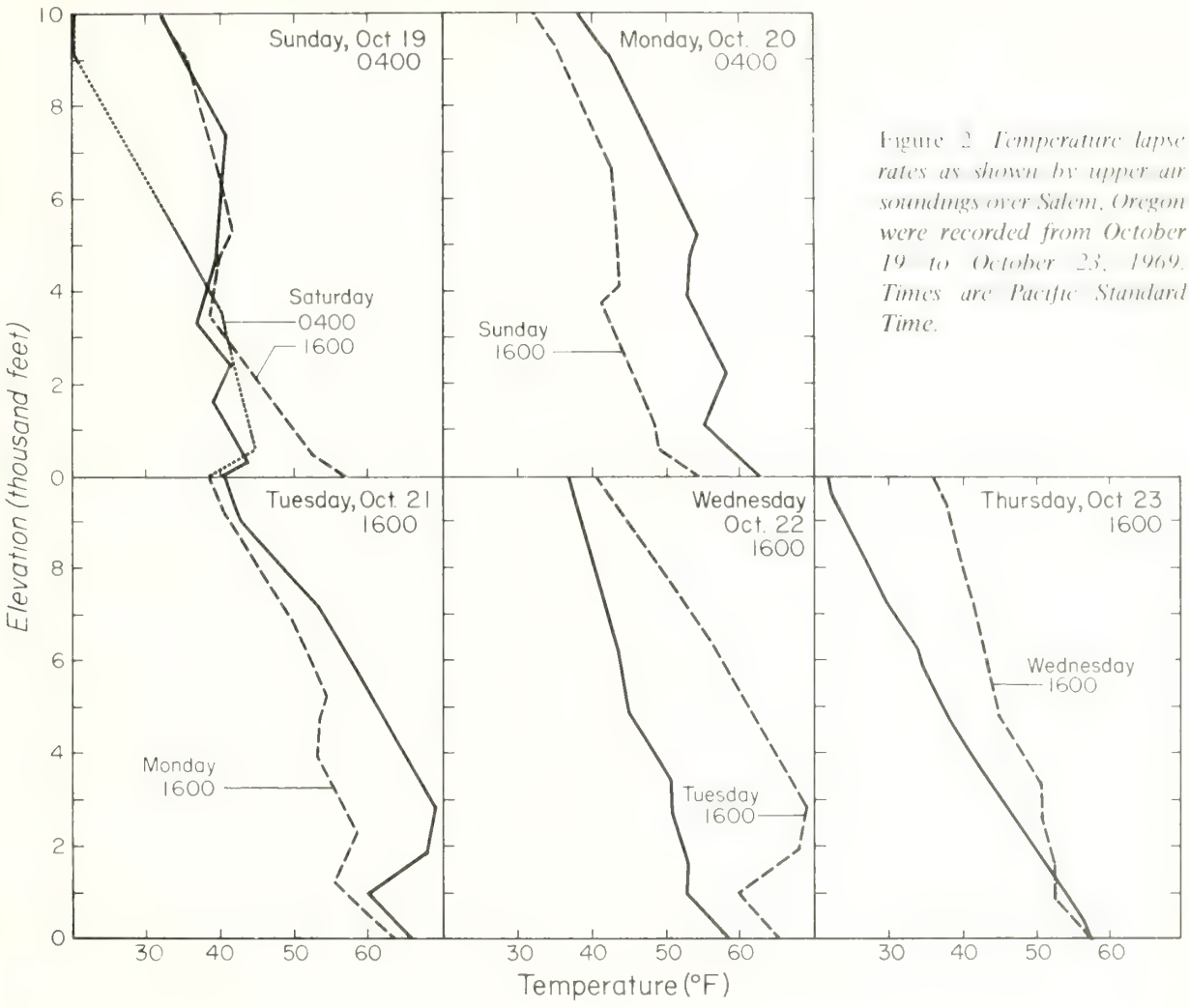


Figure 2 *Temperature lapse rates as shown by upper air soundings over Salem, Oregon were recorded from October 19 to October 23, 1969. Times are Pacific Standard Time.*

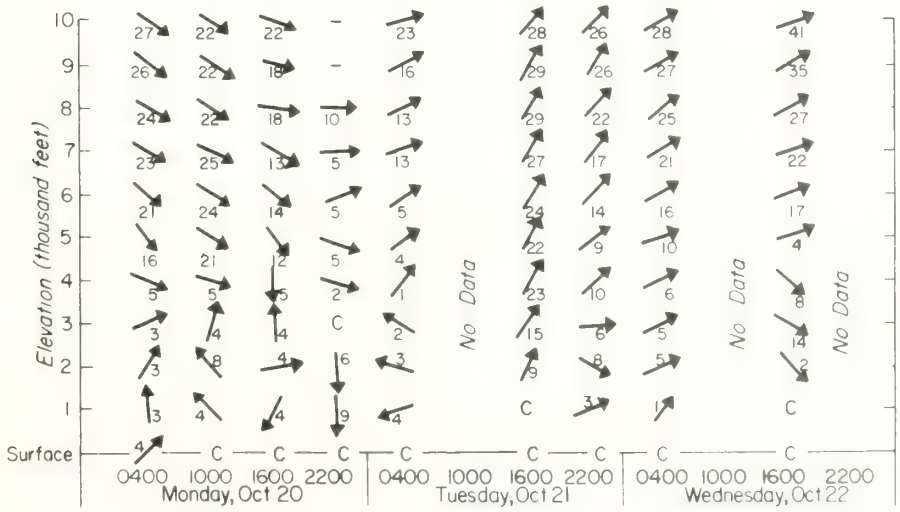


Figure 3—*Wind speeds and directions taken at Salem, Oregon to 10,000 feet (m.s.l.) from October 20 to 22, 1969.*

and beyond. This condition was caused by the eastward movement of the High away from western Oregon and the approach of cyclonic, or low-pressure, flow from the west. Subsidence in the High gave way to rising air in the Low *(fig. 2)*. At first the cooling was mainly in the lower levels, rendering the air mass more stable. During Wednesday night and Thursday, the cooling was mainly in the upper levels. The stagnant air in the Willamette Valley was dispersed by Thursday, October 23.

## SLASH BURNING AND SMOKE DISPERSAL

Almost no slash burning was done in western Oregon on the two days preceding Monday. Since midsummer there had been 6 to 8 inches of rain in the Cascades. During the 3-day period studied, varying amounts of slash were burned *(table 1)*. Burn locations for each day are shown in *figure 4*. No slash was burned in the coast range west of the Valley during this period.

Table 1–*Slash burned in western Oregon during the study period. October 20-22, 1969*

| Date | Acres burned[1] | Fuel consumed |
|---|---|---|
| | | *Tons* |
| October 20 | 819 | 54,850 |
| October 21 | 2,936 | 192,200 |
| October 22 | 2,225 | 139,250 |
| Total | 5,980 | 386,300 |

[1]For western Oregon and southern districts of Gifford Pinchot National Forest, Washington.

Very stable air conditions caused serious air pollution at this time in the Valley area below 2,600 feet. Visibility was at times less than 1 mile because of fog and smoke from local sources *(table 2)*. On Tuesday afternoon, October 21, the Columbia-Willamette Air Pollution Authority announced pollutants in the air over Portland registered 98 on a haze index scale of 0-100. The haze index is a relative measure of visibility-reducing contaminants in the air; a value of 0 indicates the lowest level of contaminants, and 100 the highest expected during the year. The index is the weighted average of individual indexes for suspended particulate (smoke and dust) and nitrogen dioxide, with the two contaminants given 85 percent and 15 percent weightings.

Table 2–*Visibility in the Willamette Valley and adjacent areas during the 3-day study period (P.s. t.)*

| Location | Visibility | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | October 20, 1969 | | | | October 21, 1969 | | | | October 22, 1969 | | | |
| | 0800 | 1200 | 1600 | 1800 | 0800 | 1200 | 1600 | 1800 | 0800 | 1200 | 1600 | 180 |
| Portland, north end of Willamette Valley | 3 mi. Smoke | 5 mi. Smoke | 7 mi. Smoke | 15 mi. | 1/16 mi. Fog and smoke | 3 mi. Smoke | 6 mi. Smoke | 6 mi. Smoke | 3/4 mi. Fog and smoke | 2 mi. Fog and smoke | 4 mi. Smoke | 4 mi Smo |
| Salem, central Willamette Valley | 1½ mi. Ground fog and smoke | 4 mi. Smoke | 6 mi. Smoke | 6 mi. Smoke | Zero Fog and smoke | 2½ mi. Smoke | 5 mi. Smoke | 5 mi. Smoke | 1/8 mi. Fog and smoke | 1 mi. Fog and smoke | 3 mi. Smoke | 4 mi Smo |
| Eugene, south end of Willamette Valley | 1/8 mi. Fog and smoke | 3 mi. Smoke | 8 mi. | 2 mi. Smoke | 1/8 mi. Fog and smoke | 1½ mi. Fog and smoke | 4 mi. Smoke | 2 mi. Ground fog and smoke | 1/8 mi. Drizzle, fog and smoke | 1 mi. Fog and smoke | 2 mi. Fog and smoke | 2 mi Grou fog a smok |
| Redmond, central Oregon, 35 miles east of Cascade crest | 45 mi. | 45 mi. | 45 mi. | 15 mi. | 35 mi. | 45 mi. | 45 mi. | 15 mi. | 45 mi. Smoky in west quadrant | 45 mi. Smoky in west quadrant | 15 mi. Smoke | 4 mi Smo |
| The Dalles, northern Oregon, Columbia River, 30 miles east of Cascade crest | 30 mi. | 30 mi. | 30 mi. | 15 mi. | 30 mi. | 30 mi. | 30 mi. | 30 mi. | 30 mi. | 20 mi. | 30 mi. | 15 m |

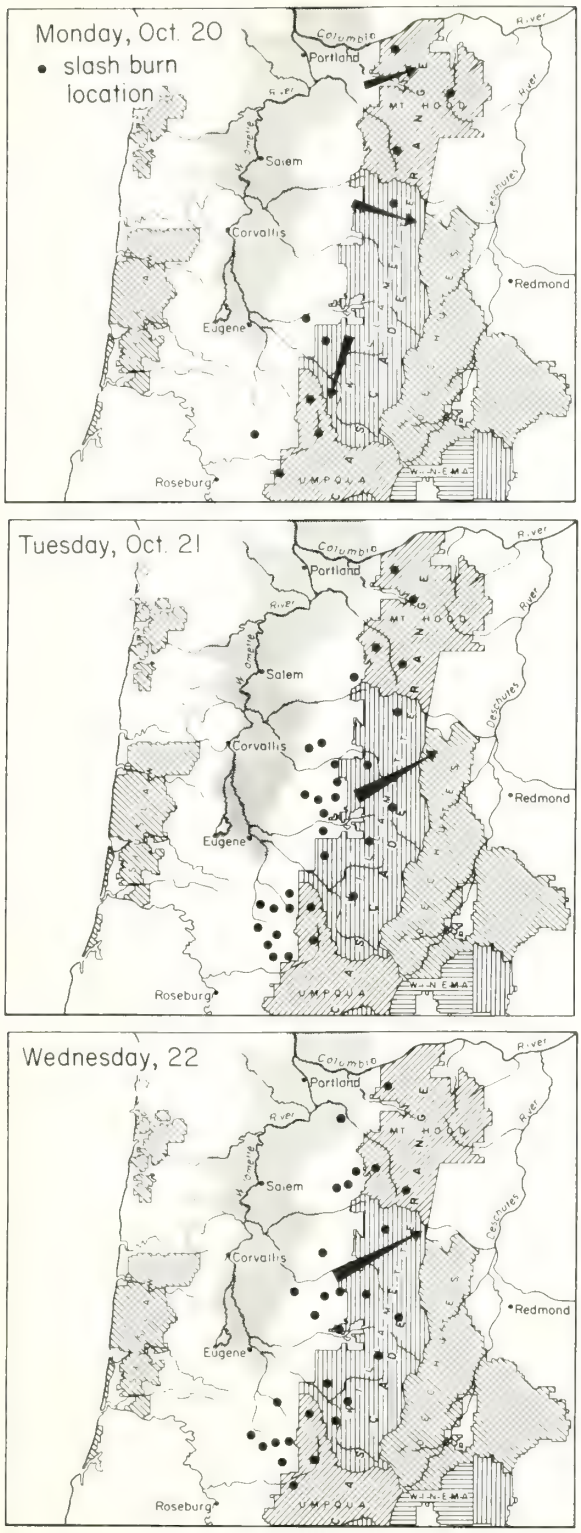


Figure 4—*Arrows show general smoke drift from slash burns as observed from aircraft during the 3-day study period. Shaded area is the Willamette Valley, in western Oregon.*

## *Monday, October 20*

On this day, 819 acres of slash were broadcast burned at widespread locations in the Cascades *(fig. 4)*. About 54,850 tons of fuel (67 tons per acre) were consumed in these burns. Peak smoke discharge was reached sometime between 1500 and 1700.

At 1600 in Salem, visibility was 6 miles in smoke from local sources in the Valley *(table 2)*. The top of a lower inversion layer was at 2,200 feet, with another inversion between 3,900 feet and 5,300 feet *(fig. 3)*.

During the observation flights made at this time, a layer of smoke could be seen near the floor of the Valley. Visibility was excellent throughout the Cascades, except for the lowest western slopes, and where scattered plumes of slash smoke were observed *(fig. 5)*. A few of these appeared to be discharging into nearly calm air, with little smoke drift. However, all plumes were drifting away from the Willamette Valley. Over the Mt. Hood National Forest, the smoke drift was east-northeast. Over the northern Willamette National Forest, the drift was east-southeast. Smoke from 434 acres of slash burning on National Forest and State land south and east of Eugene *(fig. 4)* was drifting south-southwest. All smoke plumes rose only about 500 to 1,000 feet above the ground and then drifted horizontally. The slash fires were widely spaced, and smoke impaired visibility only in the immediate areas of the burns.

The variety in direction of smoke drift in the Cascades on Monday, and the lack of correlation with observed winds over Salem *(fig. 3)*, in the Willamette Valley, is of special interest. Evidently, pilot balloon observations from stations some miles removed from mountain areas are not necessarily representative of wind flow over the mountains—at least during periods of light upper winds (say less than 12 miles per hour).

Further research must determine if reliable analyses can be made from existing observation stations, or if additional pilot balloon observations in mountain areas are needed for better smoke management.

## *Tuesday, October 21*

On this day, about 1500, slash burning activity reached its peak for the 3-day period—especially on State lands in eastern Linn, Lane, and Douglas counties *(fig. 4)*. We made no aerial observations, but a Forest Service pilot reported that smoke was dense in the Cascades, and smoke drift was again away from the Willamette Valley. On this day, 192,200 tons of slash were consumed on numerous clearcut units

totaling 2,936 acres. The Mount Hood and Willamette National Forests burned a combined total of 1,475 acres–about half the acres burned in western Oregon for the day.

At 1600, the top of the Willamette Valley inversion was 2,800 feet *(fig. 2)*. On the floor of the Valley, visibility was 4 to 6 miles in smoke from local sources.

## Wednesday, October 22

Slash burn reports for Wednesday indicated that 139,250 tons of slash were consumed on 2,225 acres *(fig. 4)*. Once again, peak burning activity was in late afternoon about 1600.

At this time, a reconnaissance flight was again made from Portland to the Eugene-Springfield area–south over the Cascades and back north to Portland over the Willamette Valley.

The situation was then rather complex. Over the Willamette Valley hung a shallow layer of low clouds with tops about 1,200 feet or possibly lower *(fig. 6)*. This layer was breaking up, revealing considerable smoke near the floor of the Valley. Immediately above this layer, visibility was excellent and the lower foothills of the Cascades were clearly visible.

Numerous smoke plumes were observed along the flight path over the west slopes of the Cascades. A few rose vertically for 1,000 feet or a little more, but most drifted almost horizontally from the source. All smoke drift was toward the east, and a dense pall covered most of the crest of the Cascades and eastward for at least 50 miles over central Oregon *(fig. 7)*. Visibility in Redmond (elevation 3,071 feet) at 1800 was only 4 miles because of smoke from slash *(table 2)*. Peaks above the 8,000-foot level were clearly visible. All slash burning was limited to areas above 2,500 feet.

From 2,500 feet to 8,000 feet, smoke was dense and widespread, although it was in two or more layers, varying with location, and with good visibility between layers. It was obvious to us that there was no relation between the slash smoke in the Cascades and the smoke on the Willamette Valley floor.

Figure 5–*Aerial view looking north, showing excellent visibility over the Mt. Hood National Forest at 1600 on Monday, October 20. Mt. St. Helens (black arrow; elevation 9,677 feet) is approximately 100 miles distant. The smoke from the slash fire, in the foreground, is being carried eastward.*

Figure 6—*Aerial view of the Willamette Valley at 1700 on Wednesday, October 22, looking northeast toward Mt. Hood (black arrow). It shows that slash smokes (white arrows) in the Cascades are not mixing with low-level clouds and smoke in the foreground area.*

## DISCUSSION

The fundamental principles governing smoke dispersion are rather simple, but the practical application of these principles to smoke management poses new problems to both meteorologists and foresters; in a sense, both are beginners.

Atmospheric stability is important to smoke dispersion. However, this study clearly shows that wind direction was also a key factor in keeping slash smoke out of the Willamette Valley. Systematic observations of slash smoke plumes should help those responsible for smoke management to increase their skills. Visual evidence should be correlated with data on both wind and stability.

The dense smoke covering the Cascades on Tuesday and Wednesday *(fig. 7)* suggests that more restrictive limitations on burn acreages and locations may be necessary. Although winds aloft carried slash smoke away from the populated Willamette Valley, the smoke was concentrated over smaller communities east of the mountains, and in the Cascades themselves. This problem although not as serious as valley pollution, must also be reckoned with.

This study did not explore the possible drift of smoke downcanyon at night. Air pollution investigators are interested in this possibility, and information should be sought. The downhill drift of smoke into the Valley in this instance was probably negligible. The marked stratification of air layers resulting from the persistent temperature inversion rendered such flow unlikely.

Limiting the number of smoke sources over the burn area should increase the likelihood of effective smoke dispersion. Exactly what this distribution should be can only be determined by further study. Amount and area of slash smoke at any given time can be described, as shown in this paper, and the best level of smoke management can be determined.

Figure 7—*Aerial photos taken on two different days over the Willamette National Forest. Both views are from the same elevation and general location, looking southeast. The arrow in each photo points to the Three Sisters peaks (elevation 10,354 feet) about 60 miles distant. Top, Monday, October 20; scattered smokes from 50 acres of burning slash (approximately 5,000 tons of available fuel). Bottom, Wednesday, October 22; smoke density from 1,250 acres of burning slash on numerous scattered clearcuts on the Willamette National Forest and adjacent state lands. The smoke shown in the photo is from approximately 80,000 tons of consumed slash fuel.*

Color 35-mm. photographs taken from light aircraft provide inexpensive case history documentation. Careful noting of camera direction and elevation helps to orient the photography. Temperature readings from a wing-tip sensor, made during ascent and descent, provide lapse rate data.

Analysis of daily slash burning reports provides useful information on smoke sources, acreages burned, and fuels consumed. This information, correlated with weather data and photo documentation,

can provide the forester with a clearer picture of smoke quantity in relation to source. Such knowledge can be directly applied to effective smoke control for prescribed burning operations.

An educational program is very much needed to dispel public misunderstanding, to assist foresters responsible for slash disposal, and to provide weather forecasters with localized data for sharpening their skill in their new responsibility as smoke management advisors.

## SUMMARY

Dell, John D., Franklin R. Ward, and Robert E. Lynott.
1970. **Slash smoke dispersal over western Oregon...a case study.** Berkeley, Calif., Pacific SW. Forest & Range Exp. Sta., 9 p., illus. (USDA Forest Serv. Res. Paper PSW-67)

*Oxford:* 332.3(795):U614.71.
*Retrieval Terms:* slash disposal; air pollution; Oregon.

A study during a 3-day period in October determined if slash burning in the Cascade Mountains of western Oregon contributed to air pollution in the Willamette Valley during very stable air conditions. Flights were made during peak slash burning periods to observe smoke density, direction of smoke drift, and effect, if any, on air quality in the Valley. Pertinent weather data for the period were analyzed for their relation to local conditions. During the 3 days, over 350,000 tons of slash was burned on clearcut areas totaling 5,980 acres.

We found that slash smoke dispersed away from the Willamette Valley, and had little influence on the already contaminated air of the Valley. Weather data for the period provides support to these observations. Case history studies such as this are valuable for improving slash smoke management techniques, and there is great need for continuing research.



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# ACCIDENT HAZARD EVALUATION AND CONTROL DECISIONS ON FORESTED RECREATION SITES

Lee A. Paine

USDA FOREST SERVICE RESEARCH PAPER PSW- 68 /1971

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*Activities of man often cause defect. Subsequent erosion increases the probability of failure.*

*Statistically predictable environmental factors, such as flooding or streambank erosion, affect the probability of failure.*

*People and property contribute to hazard–without potential loss there is no hazard.*

*Careful evaluation is required when a tree on a heavily used site shows defect with a high damage potential.*

*Recreationists fail to acknowledge hazardous situations even when a tree is obviously defective. Hollow trunks are sometimes used as food storage cabinets.*

Hazard control on public recreation sites has never been studied with the aims of determining the underlying factors involved in hazard and of providing a practical approach to a predictable and uniform level of control. As a consequence, levels of control vary drastically from one site to the next, and the effectiveness of control cannot be predicted even over large administrative areas.

This paper defines, for the first time, the factors involved in accident hazard associated with trees and their interrelationships, and provides a practical method for hazard evaluation. An understanding of the factors involved in hazard evaluation and adoption of the recommended procedures will provide more uniform levels of public safety with greater economy for the chosen level of control. The hazard evaluation procedure was made possible through extensive research and analysis of tree failure records provided by many cooperating agencies.

In this paper, hazard is defined as the expected loss from mechanical failure of a tree during the current inspection cycle—unless the probability of an accident is reduced. Hazard may thus be expressed in terms of dollars.

# UNDERSTANDING HAZARD AND HAZARD CONTROL

## *The Goal and the Problem*

The goal of hazard evaluation and control is to provide an acceptable level of public safety at minimum cost and with the least damage to the environment. Observation of many recreation sites has shown that hazard from defective or faulty trees is often higher than recognized, and that levels of hazard control vary greatly within and between sites. Some sites are overcontrolled at excessive cost and loss to the site. Few managers can be confident that they are achieving the goal as stated above.

This situation results partly from the impossibility of satisfying unrealistic directives—at any cost; partly from lack of a standard to measure performance of current control programs; and partly arises from limited tools and inadequate field procedures for rating hazard. Our objective is to improve field procedures through better understanding of the factors involved in hazard. But better tools and realistic goals and standards are also necessary to realize the potential of improved field methods.

This paper does not recommend any specific degree of control. This is an administrative decision which should rest on consideration of socially acceptable risks in relation to costs and benefits.[1] Some administrations may well decide that hazard control is not justified, or is justified only for certain use categories. But, if practiced, hazard control should meet the goals of safety, cost, and protection of the environment.

The hazard rating procedure (see the *Field Guide*) is intended to provide a consistent, realistic estimate of hazard. The many agencies which have contributed to its development will find that it can be readily adapted to their specific requirements. However, with any method of assessing hazard, the examiner should recognize that hazard is inevitably and directly dependent on the four factors included in the procedure. These factors can be ignored only at the cost of logic and predictable results.

## *Can All Hazard be Controlled?*

Trees cannot be separated into hazardous and nonhazardous groups. Nearly all trees on a recreation site have a recognizable probability of failure and involvement in an accident. And safety costs trees as well as money. Consequently, we could never create absolutely safe conditions without removing most of the trees. If we could control all probable hazard, no one would *want* absolute safety at such a cost. Many trees with recognizable hazard must be retained or the site will lose its value and usefulness. Specimen trees, expecially, will be retained even with increased risk. Safety will always be a compromise between costs of control, esthetic values, and accident losses—just as it is in automobile and in highway design.

It is high time we admit that we cannot achieve complete safety—and still provide a desirable product—any more than industry can. It is time to define our goals and standards, so that we have a basis for

[1] Administrative goals and safety standards for management of hazard control programs for recreation sites will be described in a forthcoming report.

measuring the performance of our safety programs and for evaluating efforts at improvement.

## How Much Safety?

There is absolutely no way of deciding how much safety is warranted, or what accident losses are acceptable, except by definition–an arbitrary level set by administrative policy. After the definition has been stated, a safety standard and a control decision rule can be set. Only after a realistic safety standard has been designated, can the performance of a hazard control program be gauged.

In the absence of administrative standards, an arbitrary decision rule can usefully be established at any office–and it will provide an undefined but specific degree of safety at an appropriate cost. In this case, since no safety standard is specified, no grounds exist for deciding if the achieved degree of safety is adequate, or if control costs are excessive.

In the more desirable situation, a decision rule is designed to satisfy a safety standard. Accident losses are held to an amount *defined* as being compatible with control costs and esthetic costs. Such a rule must derive from more extensive data than are available over a short period on a single district or an entire forest.

## Control Decision Rules

Decision rules are vital in any logical approach to hazard control. The examiner must decide in each situation if control is required. An action guide or decision rule is needed for deciding whether control is necessary and for attaining a consistent level of control. There are several possible rules for individual control decisions; one relies on maximum allowable hazard. The maximum hazard allowable without control work is defined as the hazard control level. The decision rule may be stated as follows: *When the expected loss from a tree is higher than the hazard control level, the hazard must be reduced.* By working to this level, the examiner aims at achieving a specific minimum level of safety. And the purpose of hazard rating is to achieve the selected level at the lowest cost to the site and budget. After each hazard has been rated, the examiner can decide immediately with the rule given above whether control is warranted.

Should his budget not permit control down to the level set, he can revise the level upward or adopt a different rule. Rules which consider varying control budgets or the esthetic and cultural values of individual trees are possible. All of the rules can be applied equally well to the basic hazard rating.

## Setting Hazard Control Levels

The hazard control level is a specific value of expected loss selected for use in a decision rule. It has nothing to do with hazard rating. If the decision rule is followed, hazard associated with any higher expected loss will be controlled. A single control level should be set for large administrative areas to promote uniformity in conditions of public safety. This single level is much easier to justify than levels which vary from district to district or forest to forest.

Until a uniform administratively defined level has been established, the examiner can set a local hazard control level by first rating a selection of trees. After deciding which trees would be controlled under current practice, the examiner can set the hazard control level equal to the rating of the lowest-rated tree judged to need control. Subsequent control decisions will then depend on whether or not each hazard rating exceeds this hazard control level.

Minor branch hazard should not be considered in setting a local hazard control level because the damage potential (and expected loss) is usually low *(tables 1,2–see pages 7,8)* In general, control of branch hazard will be minimized when working to a hazard control level.

## Good Hazard Control Practice

Good control practice starts with evaluation and preparation of sites for future use. Hazard evaluation should always be an important consideration in planning a new site. Selection of inappropriate sites and excessive costs of control can be minimized by starting hazard evaluation early.

Removal of defect is not always the best means of hazard reduction. The same degree of control can be effected by limiting access to a site or by mechanically reinforcing the tree. With specimen trees, especially, the desired hazard reduction can often be obtained by relocation of trails, fences, and facilities to reduce exposure of targets without destroying the value of the trees. Especially valuable trees warrant the expense of horticultural procedures such as bracing for reduction of hazard.

Changes in other site factors usually forebode changes in hazard. Alterations resulting from control activities, use patterns, weather cycles, and invasion by disease or insects may all affect hazard.

Consistent and economical hazard reduction depends not only on *selection of an appropriate control decision rule,* but also on *recognition* of defects and faults in trees; and *rating* of hazard.

Recognition and evaluation of defect require skill

and experience. These abilities can be improved through training and application of currently available information. But, whatever his training, an examiner must appreciate the interacting factors which determine hazard if he is to make reliable decisions.

In this discussion, we are concerned with defining these factors and clarifying their interaction.

## FACTORS IN HAZARD

Accident hazard is inherently concerned with: (a) the probability of tree failure; (b) the probability of the tree striking a target, or impact, if failure occurs; (c) the damage potential of the possible failure; and (d) the target value. If any one of these factors is minor, hazard is minimal. Hazard varies directly with each factor. Thus, if we assume they are equally important, hazard may be evaluated as the product of the four factors.

Rating hazard by this means makes it possible to rank hazardous situations. A specified hazard control level and numerical ranking of hazard provide a guide to control decisions and a basis for budgetary planning. If the budget is limiting, hazard rating makes efficient use of funds by giving priority to the worst hazards. With a specified control level, hazard rating promotes uniform levels of control throughout an administrative area.

### Probability of Failure

*Every tree will ultimately fail unless removed. The task in rating hazard is to estimate the probability of failure during a specific period.* However, we are primarily concerned with trees which, because of their visible condition, location, or some detectable defect, are unusually susceptible to failure.[2]

We are concerned only with probability of failure before the next inspection. Most failures are triggered by some critical weather situation. For a specific tree during one inspection cycle, the probability of failure is the probability of any influence (e.g., wind or snow) sufficient to cause failure. If such conditions occur about twice in every 10 years, the probability for any given year is 2/10 or 20 percent.

In estimating the probability of failure, each tree inspected should be examined both for weakening defects and for faults resulting from poor growth or location (abnormally heavy limbs, weak crotches, unusual exposure to wind, or superficial rooting). When a defect or fault is detected, the type and intensity of those conditions most likely to cause failure are estimated (e.g., 40-m.p.h. winds). The probability of failure (i.e., the probability of such weather conditions during the current inspection cycle) is then estimated.

For potential failures which might affect in-season visitors, the estimate should be based on the occurrence of critical weather conditions in-season, only. If an estimate is required for fixed property, it should be based on year-round weather conditions. Since a hazard rating is usually higher for human occupancy, an estimate will not be necessary for fixed property exposed to the same potential failure unless the property is especially valuable.

When a defect or fault is so severe that the tree may collapse under the least stress, the probability of failure will be 100 percent.

Estimating the probability of weather conditions that will cause failure is difficult. But it is exactly *the same procedure that we normally follow* in selection of trees for hazard control. We are simply defining the process and the variables.

Without probability-of-failure as a guide to control decisions, the examiner is committed to operating on the basis of some arbitrary or capricious definition of what constitutes a "dangerous" tree. And unless estimates can be expressed numerically, he is reduced to intuitive evaluations. The problem is not in expressing probabilities numerically, but rather in improving our score by attention to the basic causes of hazard.

### Probability of Target Impact

The probability of a target being struck if a particular tree fails is really a joint probability that (a) the falling tree will strike a specific area, and that (b) the area will be occupied. The probability of failure times the probability of impact is approximately the probability of an accident. Accident *loss* also depends on two components: (a) the ability of the class of failure to inflict damage, and (b) the value of the target. Thus hazard may be evaluated as the probability of an accident times the probable loss if an accident occurs, or *the expected loss this year if the hazard is not reduced.*

[2]This statement reflects the viewpoint that evaluation of tree hazard should cover all detectable or foreseeable circumstances. As methods of detection improve, our evaluations should become more critical.

### Human Occupancy

For human occupancy, I recommend that the probability of impact be taken as the probability of occupancy. When we rate a tree with a significant probability of striking an area subject to human occupancy, we thus tacitly assume that it is sure to strike the occupied unit if it fails.

For such a tree, the probability of target impact for recreationists or their effects is taken as the probability of the unit being occupied during the season of use. This probability can be expressed as the ratio of occupancy days to total season days (percentage of full season occupancy). Season days are based on the average or anticipated season of use. Unit occupancy days may be estimated for the unit or based on the average for the entire facility. Unit occupancy should represent the number of days a site is occupied by one or more persons without giving additional weight to multiple occupants.

With a season of 100 days and occupancy of a unit by one or more visitors for 75 days, the probability of target impact if a failure occurs may be estimated as unit occupancy days/season days = 75/100 = 75 percent. This estimate provides bias in favor of the recreationist since it assumes target impact if the unit is occupied at the time of failure.

For common-use facilities, such as lavatories, impact probability for human occupancy can be expressed similarly: total days utilized/season days On this basis, the probability of impact will be equal to or greater than that for any one of the camp units served by the facility. For between-unit or peripheral areas occupancy may be estimated with regard to occupancy for adjacent camp units.

### Fixed Property

For permanently situated property, the probability of occupancy is always 100 percent. Probability of target impact is simply the probability that the occupied area will be struck if the tree fails. This probability is estimated by the examiner on the basis of direction of lean, direction of prevailing winds, or other pertinent factors. The examiner may judge that, if the tree failed, it would land within an $80^{\circ}$ arc of which the fixed property occupies $20^{\circ}$. The probability of impact could then be estimated as $20^{\circ}/ 80^{\circ}$ = 25 percent.

## Damage Potential

Evaluation of the hazard or expected loss associated with an uncontrolled defect requires an estimate of the relative danger associated with each class of defect. A small limb causes less damage than a bole, and the average damage potential of a softwood bole differs from that of a hardwood bole. To provide the examiner with a guide to damage potential, two tables derived from field data supplied by cooperating agencies are included in this report. They list average loss for class of failure, d.b.h., and tree group as compared with the maximum loss expected from uprooting of a 70-inch d.b.h. softwood[3] *(tables 1,2).*

*Table 1* provides a damage potential guide for exposure of recreationists and their property. The figures are based on property losses of recreationists plus evaluation of fatalities and injuries requiring medical treatment. The 1968 losses used for evaluating personal injuries and fatalities were supplied by the National Safety Council.

*Table 2* provides guide numbers for damage to fixed property. These damage potential figures multiplied by the dollar value of the target reflect the expected property loss in an accident. The figures are based only on failures causing property damage. Losses are also related to tree species, but data now available do not permit further breakdown.

The two tables cover only the d.b.h. range of trees involved in reported accidents. As with any such experience table, the damage potential values are guides which will provide valid average estimates when correctly applied. They will not necessarily predict a particular situation accurately.

In deriving the damage potential guide tables, losses involved in accidents were first analyzed for tree species and class of failure. Groups which showed similarity were then combined as indicated in *tables 1 and 2.* Curves relating d.b.h. to loss were fitted to the data for each group and tested for best fit. To provide a multiplying factor expressing the potential for damage of a d.b.h. and failure class, each curve value for a given d.b.h. was divided by the expected loss in an accident involving the uprooting of a 70-inch d.b.h. softwood. The published guide numbers are thus derived from the fitted curves, but represent the potential for damage of any one failure class and d.b.h. as compared with that of an uprooting 70-inch d.b.h. softwood.

## Target Value

The target value may be defined as the maximum possible loss if the target is involved in an accident. However, a constant target value of $4,000 is recommended with any recreationist occupancy. This figure is based on personal injury and property losses

[3]Based on maximum size range included in *tables 1 and 2.*

resulting from tree failure accidents involving only recreationists.[4]

With fixed property, its actual value may usually be estimated in dollars for a target value. Occasionally, the target is so large that an accident involving a 70-inch tree could not result in total loss. In this case, the assigned target value is the maximum loss that would result from an uprooted 70-inch d.b.h. softwood falling on the exposed target. For example, a $30,000 building might have an estimated maximum loss of $7,000 in such an accident. It would thus be assigned a target value of $7,000.

## HAZARD RATING

Hazard is a function of the probability of tree failure, the probability of target impact, the damage potential, and the target value. We may define the *hazard rating* as the product of our estimates of these factors. For human occupancy, the rating provides an estimate of expected loss biased in favor of the recreationist. For fixed property, the hazard rating provides a direct estimate of the expected dollar loss during the current inspection cycle if the hazard is not reduced.

The rating provides an evaluation of hazard in any one situation as compared with other situations rated by the same method. Priority can be given to the highest rated hazard, with hazard reduction applied to all trees rated above the administrative hazard control level.

Our prime concern is the limitation of personal injury and property damage on controlled sites. A tree will not be subject to control if there is little or no chance of damage—unless post-failure cleanup would be more costly than control.

The Field Guide illustrates practical application of the factors involved in hazard rating and control decisions.

## DISCUSSION

### *The Examiners*

The hazard examiner requires special knowledge and experience for effective hazard rating and control. He should be trained and qualified to make the decisions required of him. Correct control decisions can limit personal injury and property losses to an acceptable minimum. At the same time they avoid removal of valuable low-hazard trees. An examiner's decision-making skills are enhanced by an appreciation of the basic factors underlying hazard and their effects. Good hazard rating estimates depend on his familiarity with recreation site pathology, his ability to recognize symptoms of tree defect or fault, and to evaluate the resulting loss of stability or strength in trees. In addition, he should be familiar with local weather patterns, and the characteristics of individual sites.

To ensure effective and consistent hazard rating throughout the administrative region, we recommend one of the following options: either (a) teams of specialists in recreation site pathology assigned to cover the entire administrative region and assisted by local personnel selected for their knowledge of local weather patterns and conditions, or (b) frequent training sessions in hazard rating for all personnel assigned to these duties. Considering the periodic reassignment of many personnel, annual sessions may well be required for the latter option.

### *Esthetic and Cultural Values of Trees*

A control decision rule can be devised to weigh the probable losses if a hazard is not controlled against the cost resulting from control. A major factor in such a rule is the value of the tree *in situ*. Valuable specimen trees may warrant retention because of their contribution to the site when less desirable trees with an equivalent hazard rating would be removed.

Such a rule is more difficult to apply—it requires an estimate of the value of the tree or its contribution to the site. Cost-based guides have been developed for shade tree evaluation, and their application to hazard control decisions is being considered by the Pacific Southwest Forest and Range Experiment Station. In the meantime, low-value trees should be given especially careful attention. Their removal may be justified even though their hazard rating falls below

[4]Records derived from over 300 reported accidents occurring west of the Mississippi River during approximately 3 years (1966-1969).

the control level. Conversely, if this rule were applied, high-value trees would sometimes be retained even though associated with high hazard.

## Public Responsibility and the Law

It is absolutely possible to limit accidents directly and logically to any desired degree—at a cost. But accidents will occur as long as people and property are exposed to the effects of tree failures. We can only limit the rate of accidents by modifying the acceptable limits of hazard.

Since not all hazardous trees will be removed, we must expect some preventable failures and some preventable accidents on forested recreation sites. A safety standard and hazard control level can set a reasonable upper limit.

Trees rated below this level may still fail, of course. Should one cause an accident resulting in court action, it would provide a situation in which some degree of hazard was recognized but no control was instituted. Of course, this has been happening in the past, but such trees were not recorded. Nor is there any operational necessity for recording a hazard rating unless it falls above the hazard control level requiring future action.

No one can presently foresee a court's reaction to the fact that a continuous range of hazard exists on occupied recreation sites, and that to eliminate all hazard means to remove all people and property or else to do away with the trees. But we may consider the following points: (1) Some predictable hazard is associated with every tree on an occupied recreation site; (2) improved examination and rating procedures with the removal of all hazard rated above the control level would result in a safer environment for the recreationist; (3) the costs or losses involved in removing hazard below the control level are presumably prohibitive; and (4) because people are invited to use a site where hazard exists, we must accept the probability of a certain number of accidents all of which would have been preventable.

If we accept the challenge of providing the best available protection to the public, we must also accept the fact that (recognized) low hazard trees can cause accidents with a risk of official but unjustified embarrassment. It seems a small risk as compared with the opportunity for making significant improvements in public safety and reducing the over-all property losses and personal injuries at reasonable costs.

*Failures and accidents may occur without apparent defect or detectable fault in the tree. But hazard can be evaluated for sound as well as for defective trees.*

# FIELD GUIDE TO
# HAZARD RATING AND CONTROL DECISIONS

Hazard is rated as the product of the probability of failure, the probability of impact, the damage potential of the possible failure, and the target value. Control is indicated when the hazard rating for an individual tree exceeds an established control level.

The following steps are recommended for rating tree hazard on recreation sites.

## *Recreationist Occupancy*

(1) *Select for examination each tree which might pose an appreciable hazard* to people or property on controlled sites. (On some sites this may include all trees.)

(2) *Examine the tree for defects or faults.* (If none is found, pass the tree.)

(3) *Estimate the type and intensity of critical weather conditions,* depending on the severity of defect or fault, which will result in failure of the tree (e.g., 40-m.p.h. wind).

(4) *Estimate the probability of failure in-season* (i.e., frequency of critical weather conditions during season that site is occupied by recreationists). For example, an estimated two in-season occurrences in every 10 years or 2/10 = 20 percent probability of failure for one season.

(5) *Estimate probability of recreationist occupancy* during average season; e.g., 75 occupancy days/100 season days = 75 percent.

(6) *Determine damage potential* for appropriate tree group and class of potential failure using *table 1* for recreationist occupancy.

(7) *Estimate target value* (use $4,000 for recreationist occupancy).

(8) *Multiply values in (4), (5), (6), and (7)* for the hazard rating.

(9) *Mark tree for control* if hazard rating exceeds the hazard control level.

(10) *Examine adjacent trees* for any rating change which will result from control of hazardous tree.

Table 1—*Guide numbers indicating relative potential of softwoods and hardwoods for damage to recreationists and their property, by tree size and defect class*[1]

| Diameter breast height (inches) | Softwoods | | | Diameter breast height (inches) | Oak[2] | | Other hardwoods[2] | |
|---|---|---|---|---|---|---|---|---|
| | Limb | Upper bole | Lower bole, butt, or root | | Limb | Lower bole, butt, or root | Limb | Lower bole, butt, or root |
| 10 | – | 0.055 | 0.055 | 10 | – | – | – | – |
| 12 | – | .065 | .065 | 15 | – | – | – | 0.065 |
| 14 | – | .07 | .07 | 20 | 0.025 | 0.10 | 0.07 | .07 |
| 16 | – | .08 | .08 | 25 | .06 | .10 | .08 | .10 |
| 18 | – | .09 | .09 | 30 | .09 | – | .08 | .13 |
| 20 | – | .10 | .10 | 35 | .12 | – | – | .16 |
| 22 | – | .12 | .12 | 40 | .16 | – | – | .19 |
| 24 | – | .13 | .14 | 45 | .21 | – | – | .22 |
| 26 | – | .14 | .16 | 50 | .27 | – | – | – |
| 28 | – | .15 | .19 | 55 | .33 | – | – | – |
| 30 | 0.12 | .16 | .23 | | | | | |
| 32 | .12 | .17 | .28 | | | | | |
| 34 | .12 | .18 | .33 | | | | | |
| 36 | .12 | .18 | .38 | | | | | |
| 38 | .12 | .18 | .44 | | | | | |
| 40 | .12 | .18 | .49 | | | | | |
| 42 | .12 | .18 | .55 | | | | | |
| 44 | .12 | .18 | .60 | | | | | |
| 46 | .12 | – | .66 | | | | | |
| 48 | .12 | – | .71 | | | | | |
| 50 | – | – | .76 | | | | | |
| 52 | – | – | .80 | | | | | |
| 54 | – | – | .84 | | | | | |
| 56 | – | – | .88 | | | | | |
| 58 | – | – | .91 | | | | | |
| 60 | – | – | .94 | | | | | |

[1]Includes data for pine, fir, Douglas-fir, and the cedar family as well as oak and hardwoods other than oak.
[2]No upper bole recreationist losses reported for oak or other hardwoods. Figures for oak and other hardwoods based on limited data which reflect no injuries or fatalities.

## Fixed Property

With valuable fixed property exposed throughout the year, the probable loss may warrant control of hazard. In rating hazard with regard to fixed property, the first three steps are the same as in the procedure used for recreationist occupancy.

(1) *Select for examination each tree which might pose an appreciable hazard* to people or property on controlled sites. (On some sites this may include all trees.)

(2) *Examine the tree for defects or faults.* (If none is found, pass the tree.)

(3) *Estimate the type and intensity of critical weather conditions,* depending on the severity of defect or fault, which will result in failure of the tree (e.g., 40-m.p.h. wind).

(4) *Estimate the probability of failure* during entire year (frequency of critical conditions per year). For example, an estimate of four critical wind storms in 10 years or 4/10 = 40 percent for 1 year. The probability of failure for year-long exposure of fixed property will always equal or exceed that for the shorter period of seasonal recreationist occupancy.

(5) *Estimate probability of impact* for fixed property. For example, the proportion of probable impact arc occupied by fixed property = $20^{o}/ 80^{o}$ = 25 percent.

(6) *Determine damage potential* for appropriate tree group and class of potential failure using *table 2* for fixed property.

(7) *Estimate target value.* If target would be less than a total loss if struck by a 70-inch d.b.h. softwood, the estimated loss for such an accident is taken as the target value.

(8) *Multiply values in (4), (5), (6), and (7)* for the hazard rating. If tree is also rated for recreationist occupancy, use higher of two ratings.

(9) *Mark tree for control* if hazard rating exceeds the administrative hazard control level.

(10) *Examine adjacent trees* for any rating change which will result from control of hazardous tree.

Table 2—*Guide numbers indicating relative potential of softwoods and hardwoods for damage to fixed property, by tree size and defect class*[1]

| Diameter breast height (inches) | Softwoods | | | Diameter breast height (inches) | Oak[2] | | Other hardwoods[3] | |
|---|---|---|---|---|---|---|---|---|
| | Limb | Upper bole | Lower bole, butt, or root | | Limb | Lower bole, butt, or root | Limb | Lower bole, butt, or root |
| 10 | – | 0.025 | 0.025 | 10 | – | – | – | 0.065 |
| 12 | – | .03 | .03 | 15 | – | 0.04 | – | .065 |
| 14 | | .03 | .03 | 20 | 0.018 | .06 | – | .065 |
| 16 | – | .04 | .04 | 25 | .025 | .08 | – | .065 |
| 18 | – | .05 | .05 | 30 | .05 | .14 | – | .065 |
| 20 | | .07 | .07 | 35 | .09 | .20 | – | .065 |
| 22 | | .08 | .08 | 40 | .12 | .29 | – | .065 |
| 24 | 0.035 | .09 | .10 | 45 | .15 | – | – | .065 |
| 26 | .035 | .11 | .12 | 50 | .17 | – | – | .065 |
| 28 | .035 | .12 | .14 | 55 | .19 | – | – | – |
| 30 | .035 | .12 | .16 | | | | | |
| 32 | .035 | .13 | .19 | | | | | |
| 34 | .035 | .13 | .22 | | | | | |
| 36 | .035 | .13 | .26 | | | | | |
| 38 | .035 | .13 | .31 | | | | | |
| 40 | .035 | .14 | .36 | | | | | |
| 42 | .035 | .14 | .42 | | | | | |
| 44 | .035 | .14 | .47 | | | | | |
| 46 | .035 | .14 | .53 | | | | | |
| 48 | .035 | .14 | .58 | | | | | |
| 50 | .035 | – | .64 | | | | | |
| 52 | .035 | – | .69 | | | | | |
| 54 | .035 | | .74 | | | | | |
| 56 | .035 | – | .79 | | | | | |
| 58 | .035 | – | .84 | | | | | |
| 60 | .035 | – | .88 | | | | | |
| 62 | – | – | .91 | | | | | |
| 64 | | – | .94 | | | | | |
| 66 | – | – | .97 | | | | | |
| 68 | – | – | .99 | | | | | |
| 70 | | – | 1.00 | | | | | |

[1]Includes data for pine, fir, Douglas-fir, the cedar family, spruce, and hemlock, as well as oak and hardwoods other than oak.

[2]Insufficient data for upper bole. Suggest using limb values for oak upper bole.

[3]Insufficient data for limb and upper bole.

| Tree No. | Occupancy | Species group[1] and d.b.h. (inches) | Potential failure class | Probability of tree failure | | Probability of impact | | Damage potential guide number | | Target value[2] (dollars) | Hazard rating | Control recommended |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | In season | Annually | Human occupancy | Fixed property | Human occupancy | Fixed property | | | |
| 1 | lavatory | S(40) | limb | 0.10 | — | 0.80 | — | 0.12 | — | 4,000 | 38 | |
| 2 | service building | H(30) | root | — | .60 | — | .40 | — | .065 | 800 | 12 | |
| 3 | sign | S(24) | butt | — | .90 | — | .90 | — | .10 | 100 | 8 | |
| 4 | pumphouse | S(36) | limb | — | .70 | — | .80 | — | .035 | 500 | 10 | |
| 5 | recreationist | H(34) | lower bole | .70 | — | .40 | — | .16 | — | 4,000 | 179 | ✓ |
| " | unit property | " | " | — | .80 | — | 1.00 | — | .065 | 500 | 26 | |
| 6 | recreationist | H(25) | lower bole | .40 | — | .50 | — | .10 | — | 4,000 | 80 | |
| 7 | recreationist | S(18) | butt | .60 | — | .70 | — | .09 | — | 4,000 | 151 | ✓ |
| 8 | recreationist | S(28) | limb | .10 | — | .70 | — | .12 | — | 4,000 | 34 | |
| 9 | summer residence | S(24) | butt | .40 | — | .90 | — | .14 | — | 4,000 | 202 | ✓ |
| | | | | | | | | | | | | |

[1]S = softwood; O = oak; H = other hardwoods. [2]Human occupancy = $4,000.

Figure 1—*A worksheet illustrates the use of the field guide in rating tree hazard with the hazard control level = 100.*

## *Worksheet*

A worksheet *(fig. 1)* illustrates use of the guide with a hazard control level set at 100. A worksheet may not be needed in practice since the simple multiplication can be done on scratch paper. Tree 1—a 40-inch d.b.h. ponderosa pine—was examined because it is in position to threaten a lavatory.

- A defective limb was found. Since the lavatory is used seasonally and exposed throughout the year, two ratings are possible but hazard was rated only for human occupancy.
- Probability of failure in-season was estimated at 10 percent (0.10).
- The examiner estimated that the lavatory would be used 100 days of the 125-day season. Probability of impact (recreationist occupancy) = 100/125 = 80 percent (0.80).
- The damage potential of a ponderosa pine limb is 0.12 for recreationist occupancy *(table 1)*.
- The target value is $4,000 for recreationist occupancy.
- The product of the four values (0.1 X 0.8 X 0.12 X $4,000) to the nearest dollar is $38 and does not exceed the hazard control level of $100.
- Decision: no control recommended.

A tree threatening a unit subject to recreationist occupancy should first be rated for this situation. The rating for fixed property occupancy is usually lower, and will not ordinarily be needed if hazard has been rated for recreationist occupancy. In unusual situations, making both ratings may compensate for the extra costs of inspection.

Trees 2, 3, and 4 require only a fixed property rating if human occupancy is considered minimal.

# SUMMARY

Paine, Lee A.
1971. **Accident hazard evaluation and control decisions on forested recreation sites.** Berkeley, Calif., Pacific SW. Forest & Range Exp. Sta., 10 p., illus. (USDA Forest Serv. Res. Paper PSW-68)

*Oxford:* 907.2:304:416.
*Retrieval Terms:* forest safety; hazard evaluation; accident prevention; recreation sites; dangerous trees; defective trees; recreation site pathology.

This paper reports a study of the factors in recreation site hazard and the problems in providing an acceptable level of public safety. It defines, for the first time, the factors involved in accident hazard associated with trees and their interrelationships, and provides a practical method for hazard evaluation. Data for the study were supplied by cooperating public agencies.

The goals were to (a) define the major factors contributing to hazard on forested recreation sites, (b) interpret the interrelationships of these factors and their effects on hazard, (c) develop experience tables which would permit realistic appraisal of hazard, and (d) design a practical guide to hazard rating and control decisions for field examiners.

Hazard is defined as the expected loss from mechanical failure of a tree during the current inspection cycle—unless the probability of an accident is reduced. Thus hazard may be expressed in terms of dollars. The major contributing factors include the probabilities of mechanical failure and of target impact if failure occurs, the damage potential of the failure, and the value of the target. Hazard is directly related to each of these four factors, and may be evaluated as their combined product. Tables on damage potential for recreationist occupancy and for fixed property permit a direct field rating of hazard.

The field guide included in this paper provides an orderly consideration of each of the factors involved in hazard and a numerical rating of the individual tree being inspected. Control decisions are based on a comparison of the individual hazard rating with a hazard control level that is administratively pre-set.

| Tree No. | Occupancy | Species group[1] and d.b.h. (inches) | Potential failure class | Probability of tree failure | | Probability of impact | | Damage potential guide number | | Target value[2] (dollars) | Hazard rating | Control recommended |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | In season | Annually | Human occupancy | Fixed property | Human occupancy | Fixed property | | | |
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Paine, Lee A.

1971. **Accident hazard evaluation and control decisions on forested recreation sites.** Berkeley, Calif. Pacific SW. Forest & Range Exp. Sta., 10 p., illus. (USDA Forest Serv. Res. Paper PSW-68)

Accident hazard associated with trees on recreation sites is inherently concerned with probabilities. The major factors include the probabilities of mechanical failure and of target impact if failure occurs, the damage potential of the failure, and the target value. Hazard may be evaluated as the product of these factors; i.e., expected loss during the current inspection cycle unless hazard is reduced. A practical approach to hazard rating is described. Tables on damage potential for recreationist occupancy and for fixed property are included in the field guide.

*Oxford:* 907.2:304:416.

*Retrieval Terms:* forest safety; hazard evaluation; accident prevention; recreation sites; dangerous trees; defective trees; recreation site pathology.

Paine, Lee A.

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Accident hazard associated with trees on recreation sites is inherently concerned with probabilities. The major factors include the probabilities of mechanical failure and of target impact if failure occurs, the damage potential of the failure, and the target value. Hazard may be evaluated as the product of these factors; i.e., expected loss during the current inspection cycle unless hazard is reduced. A practical approach to hazard rating is described. Tables on damage potential for recreationist occupancy and for fixed property are included in the field guide.

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# AUSTRALIAN TOON PLANTED IN HAWAII: tree quality, growth, and stocking

Herbert L. Wick Robert E. Nelson Libert K. Landgraf

USDA FOREST SERVICE RESEARCH PAPER PSW-69 1971

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Figure 1—*Areas of pahoehoe were often grass-covered. Here (foreground) seedling planted to Australian toon survival was poor and growth slow in contrast to higher survival and rapid growth on aa sites (background).*

Figure 2—*Multiple branching at a node, is a common characteristic of Australian toon, limits log length. If it occurred below 12 feet the tree was classed as a cull.*

Australian toon *(Toona australis)* is used extensively for reforestation in Hawaii. Since 1959, some 5,000 acres of ohia rain forest in the Waiakea and Olaa Forest Reserves, island of Hawaii, have been converted to Australian toon plantations through land clearing and hand planting. About 250,000 Australian toon seedlings are planted annually. They are generally planted on a 10- by 10-foot spacing at the rate of 436 per acre in pure stands, but occasionally in mixture with tropical ash *(Fraxinus uhdei),* Queensland-maple *(Flindersia brayleyana),* saligna eucalyptus *(Eucalyptus saligna)* or other species. On a few sites, natural reproduction of koa *(Acacia koa)* has become an important stand component.

Australian toon seedlings can vary considerably in growth form and in growth rate—even within short distances. Natural differences in site conditions and the growth characteristics of the species probably combine to produce patchy stands with many stems of less than acceptable growth rate and quality. On some sites, they may grow well for a year or two after planting, then decline in growth rate and begin to deteriorate. The branching habit of some trees may be a significant factor limiting future stem quality.

If we can identify early in the stand's life those trees which will likely be of low quality in the mature stands, we can develop criteria for stand improvement. We need to know the number of seedlings to plant to obtain desired stocking. And if we can relate survival and growth to site factors, we would be able to develop more precise guidelines for selecting areas for land clearing and reforestation.

The paper reports a study of the condition of the young (5- to 8-year-old) plantations of Australian toon, Australian toon-tropical ash, and Australian toon-koa to determine levels of stocking and tree growth and quality, and how these levels are related to site factors. The site factors studied were soil depth, microtopography class, soil drainage class, and kind of parent rock. The seedlings were planted from 1961 to 1965.

## STUDY SITES

The plantations lie on the lower east slope of Mauna Loa on the island of Hawaii, between 800 and 3,100 feet elevation. Lava flows of different kinds and ages account for topographic differences. Microrelief is rough. The soils are acid and mostly extremely stony silt loam, such as Koloa extremely stony muck. Soils within short distances differ widely, especially in soil depth. Annual rainfall ranges from 170 inches at the lower elevation to 200 inches at the upper elevations.

Before clearing, ohia *(Metrosideros collina),* tree-fern *(Cibotium* spp.*),* and false staghorn fern *(Dicranopteris* spp.*)* were the dominant vegetative cover, but many other species were present, including such undesirable introduced species as Malabar melastome *(Melastoma malabathricum),* guava *(Psidium* spp.*),* lemi-wai *(Passiflora ligularis),* and melochia *(Melochia indica).*

Plantings have generally been made in 40-acre blocks, identifiable by surrounding access roads. Reforestation records enabled us to determine the dates of planting.

# METHODS

Sample plots were randomly set up in seedlings planted each year from 1961 to 1965. All plots included Australian toon; a few plots also included koa or ash:

| *Date planted* | *Plot No.* | *Elevation (feet)* | *Annual precipitation (inches)* |
|---|---|---|---|
| 1961: | | | |
| April | 1 | 1,100 | 175 |
| May | 3 | 1,800 | 190 |
| June | 2 | 1,000 | 170 |
| June | 4 | 1,200 | 175 |
| 1962: | | | |
| July | 7 | 1,700 | 190 |
| July | [1]8 | 1,800 | 195 |
| August | 5 | 3,000 | 180 |
| August | [2]6 | 3,000 | 180 |
| 1963: | | | |
| January | [1]10 | 1,800 | 190 |
| July | [2]9 | 2,800 | 190 |
| October | 11 | 1,100 | 175 |
| December | 12 | 1,200 | 180 |
| 1964: | | | |
| January | 15 | 1,700 | 190 |
| February | [2]13 | 3,100 | 180 |
| March | [2]16 | 2,500 | 195 |
| August | 14 | 2,700 | 190 |
| 1965: | | | |
| March | 17 | 1,200 | 175 |
| March | 18 | 1,600 | 190 |

Each sample plot was a 1/2-acre strip (33 ft. by 660 ft.) oriented perpendicular to the general lava flow pattern, in order to intercept a variety of site conditions. In November 1968, each surviving planted tree and koa tree on a plot was located, measured, and evaluated for quality. Four site factors in the immediate vicinity of each tree were recorded:

- *Soil depth:* determined by probing with a steel rod, and recorded as maximum depth of several probings around the tree. Because of extreme rockiness, the measure is an approximation. Exploratory digging showed that soil depth or volume of soil material may be extremely variable within short distances.
- *Parent rock:* most of the area sampled was aa lava. Some was obviously pahoehoe. In places, shallow soil on compacted aa may have been recorded as pahoehoe.
- *Drainage:* classed as adequate or as poorly drained (wet, boggy).
- *Topography:* Microrelief was classed as swale, side slope, ridge, or level. The study site had no major ridges or canyons.

The sample data collected were first analyzed to determine levels of stocking (survival of planted trees) and its quality. Stocking estimates were based on the trees tallied on the plots. Stocking is the residual from an assumed[3] initial planting of 436 trees per acre plus any koa reproduction. Each tree was graded and placed in one of three tree quality classes:

- *Desirable:* a growing stock tree of commercial species having no serious defects, of good vigor and having no serious pathogens; the type of tree forest managers try to grow. Specifically, the tree must have now or potentially a sawlog length of more than 32 feet; less than 4 inches sweep or crook in the butt 16 feet; no scale reducing seams, rot, splits, or cracks; and a clear panel at least 8 feet long in the poorest of the best three faces in the butt log.
- *Acceptable:* growing stock trees not meeting the specifications for desirable trees but having, now or potentially, a butt sawlog length of at least 12 feet and not culled due to forking, sweep, crook, or other factor indicated below.
- *Cull:* trees having characteristics which prevent them from being classed as desirable or acceptable. Trees were classed as cull if they had one or more of the following characteristics: (a) Lodged or arched over; (b) stem lean of more than 8 degrees; (c) fork below 12 feet; (d) heavy branching below 12 feet having the effect of forking or excessive taper; and (e) overtopped and of low vigor.

Chi-square techniques were used to test the effect of site factors on stocking and quality. For the test we hypothesized that if site factors did not affect stocking or quality, then the number of trees found on a given kind of site would be proportional to the area occupied by this site. For example, if 10 percent

[1]This plot is a mixture of Australian toon and koa. The koa component is from natural regeneration.

[2]This plot is a mixture of Australian toon and tropical ash.

[3]We assumed that 436 seedlings were planted per acre on the basis of Hawaii Division of Forestry records. No post-planting surveys were made to determine the actual number planted. We cannot infer that 436 trees were planted in each acre on a well controlled 10- by 10-foot spacing.

of the area was pahoehoe, 10 percent of the stocking would be expected to be found here. This expected value would be compared with the actual number of trees found on pahoehoe. Estimates of areas with different site factors were developed from scale maps of the plots.

# RESULTS

## Stocking

Twelve of the sample plots were in pure toon stands; stocking averaged 236 trees per acre, and ranged from 46 to 376 trees per acre *(table 1)*. In the four plots of mixed Australian toon-tropical ash, the Australian toon averaged 127 trees per acre and the tropical ash 200 per acre. In the two plots with mixed Australian toon and koa, the Australian toon averaged 306 per acre and the koa 94 trees per acre. The koa was not, however, located uniformly over the transect, but clustered around parent trees. Over-all, of the original planting of 436 trees per acre, an average of 274 trees have survived.

Soil parent rock, microtopography, soil depth, and soil drainage class all had a highly significant[4] effect on the distribution of stocking.

*Parent rock:* more seedlings than expected were found on aa and broken pahoehoe and less seedlings were found on pahoehoe than expected *(table 2)*.

*Soil drainage class:* only 4 percent of the sample area was considered poorly drained. There were only about half as many trees on the poorly drained soils as we expected *(table 2)*.

*Microtopography:* more stocking than expected occurred in swales and on ridges and less than expected occurred on the level topography and on side slopes *(table 2)*. Swales and ridges make up only 12 percent of the sample area.

*Soil depth:* if soil depth were a factor in stocking, we would expect greater stocking in deep soils than in shallow soils. But we found no consistent relationship: we counted more seedlings than expected in the shallow (0 to 12 inches) soils, less than expected in the intermediate (12 to 24 inches) soils, and more than expected in the deep (25 inches or more) soils *(table 2)*. Soil depth measurements appear to be questionable because of the nature and variability—mainly rockiness—of these plantation soils. Only 2 percent of the area is in the deep soil class.

[4]In this paper "significant" means statistically significant at the 5 percent probability level, and highly significant means statistically significant at the 1 percent level.

## Combination of Factors

Besides testing the effect of a single site factor on stocking, we combined factors. We found that these combinations had a highly significant effect: (a) microtopography class combined with soil depth, with drainage class, and with parent rock; (b) soil depth class combined with drainage class, with parent rock, and with drainage class and parent rock; (c) drainage class with parent rock *(tables 3, 4, 5)*.

If we assume that a uniform number of seedlings were planted initially on each acre, stocking was higher proportionally than would be expected on these types of soils: (a) shallow soil: swales, level, and ridges; well drained; aa and pahoehoe; (b) medium soils: swales and ridges; (c) deep soil: all microtopography classes; well drained; aa and broken pahoehoe. And stocking was less proportionally than would be expected on these types of soils: (a) shallow soil: side slopes; poorly drained; pahoehoe; (b) medium soil: level, side slopes, and ridges; poorly drained; pahoehoe; (c) deep soils: pahoehoe.

## Quality of Stocking

Australian toon trees were generally of better quality than the tropical ash or the koa—31 percent of the Australian toon trees were classified as desirable and 43 percent as acceptable. Only 26 percent of the Australian toon trees were classified as culls, while 64 percent of the tropical ash and 58 percent of the koa were classed as culls. Only about 11 percent of the ash and koa trees were rated desirable.

Species differed widely in cause for culling *(table 6)*. Forking below 12 feet was the major cause for culling Australian toon (56 percent of trees culled) and tropical ash (81 percent of trees culled). Excessive lean, the second major culling factor, accounted for 30 percent of the Australian toon cull trees, 13 percent of the tropical ash cull trees, and 36 percent of the koa cull trees. Other causes for culling were lodging, low vigor; and excess branching.

Parent rock, drainage class, and microtopography are the site factors which were significantly related to

tree quality *(tables 7, 8)*. Soil depth class, however, did not appear to be significantly related to tree quality class.

### Stocking Distribution

Since distribution of stocking is important to the development of forest stands, we measured this by counting stocked quadrats in the measured plots *(table 9)*. The data suggest that:

- If 400 well distributed desirable or acceptable trees, or both, per acre is the goal, stocking averaged only 38 percent. This measure of stocking showed a range from 12 percent to 66 percent. Only a small part of the lack of stocking can be attributed to site factors of poor drainage or pahoehoe rock.
- If 100 well distributed desirable or acceptable trees, or both, per acre is the goal, stocking averaged 75 percent. By this measure, one transect plot was fully stocked. If 100 well distributed desirable trees per acre is the goal, stocking averaged only 41 percent, ranging from 10 percent to 87 percent.

Site factors influence stocking distribution, but inconsistencies mask the degree of influence.

### Tree Growth

In general, diameter and height growth of the acceptable and desirable trees has been good *(table 10)*. In Australian toon stands, the average annual diameter growth was 0.51 inch, with a range between plots of 0.3l to 0.76 inch. Average annual height growth was 3.9 feet, with a range between plots of 2.2 to 6.0 feet. In mixed Australian toon-tropical ash stands, the ash had an annual diameter growth of 0.44 inch and an annual height growth of 4.3 feet. The average rate of growth of acceptable and desirable koa trees exceeded that of Australian toon or tropical ash: diameter growth–0.76 inch; height growth–6.7 feet.

## DISCUSSION

One objective of this study was to determine the number of desirable and acceptable trees in the young planted stands. In the pure toon stands sampled, the stocking in desirable trees ranged from 14 to 228, averaging 75 trees per acre *(table 1)*. The number of acceptable trees averaged 98 per acre. Thus the present stocking of desirable and acceptable trees (173 per acre) represents only 40 percent of an assumed initial planting of 436 seedlings per acre.

The number of cull trees in the pure Australian toon stands averaged about 63 trees per acre. This, combined with the acceptable and desirable trees, gives on the average 236 trees per acre. This represents only 54 percent of an assumed initial planting of 436 seedlings per acre.

We believe that one objective of reforestation work should be to attain a specified stocking level. Perhaps 400 acceptable and desirable trees per acre, well distributed over the area, would be a desirable stocking level for sapling and pole stands. Results of this study suggest that about 1,000 seedlings should be planted initially per acre to achieve that goal. If adequate survival can be assured, it might be possible to plant as few as 600 seedlings initially per acre to reach that stocking level. Such a possibility is suggested by data from experimental spacing plots on the Waiakea Forest Reserve, island of Hawaii.[5] In these trials, survival of 8-year-old plantations averaged more than 90 percent, although the seedlings were considered inferior at the time of planting. The high survival rate could be attributed to careful planting and to weeding about 9 months after planting. About 80 percent of the trees were rated desirable or acceptable.

Even if the minimum goal is 100 acceptable or desirable trees per acre, well distributed over the area, more seedlings must be planted initially or greater survival obtained. Only 1 of the 12 toon plots had this level of stocking distribution.

The four mixed toon-ash stands sampled averaged 52 desirable and 108 acceptable trees per acre. There were proportionally fewer cull toon trees than ash trees. Sample data were not adequate to estimate survival rates for tropical ash. However, the high proportion of cull ash trees indicate a need to plant more ash seedlings initially to achieve desired stocking.

Two of the toon stands had natural regeneration of koa. In these stands the number of desirable and acceptable toon trees averaged 241 per acre, or 55 percent of the initial planting. There were 64 cull toon trees per acre. Stocking of koa trees averaged 11 desirable, 28 acceptable, and 56 cull trees per acre. However, koa reproduction is patchy and sporadic so there is no inference intended that koa occurs throughout the stands at this level of stocking.

[5]Unpublished data on file at Pacific SW. Forest & Range Exp. Sta., U.S. Forest Service, Honolulu, Hawaii.

A second objective of this study was to relate site factors to stocking and to tree quality. All four site factors measured (microtopography, soil depth, drainage class, and parent rock) significantly affected stocking. All these factors except soil depth were significantly related to tree quality. Parent rock and drainage class seem to be of the most practical importance.

On areas of poor drainage and pahoehoe parent rock there were fewer seedlings than expected, growth was slower, and quality was lower. It should be possible and practical to avoid clearing and planting areas of poor drainage or pahoehoe rock that are large enough to be identified. Survival and quality were generally better on the deeper soils, well-drained soils, and soils on aa and broken pahoehoe.

Elevation, date of planting or weather, and other factors may also affect stocking and growth. Data collected were not sufficient for analysis of these and other variables.

## RECOMMENDATIONS

This study has developed the first quantitative information about stocking and quality of planted stands in the Waiakea-Olaa reforestation area. On the basis of the results, we recommend that. . .

1. Areas of pahoehoe, shallow soils on compacted aa, or poorly drained areas should not be planted with Australian toon or tropical ash.

2. A large number (600 to 1,000) of seedlings should be planted per acre and tended, including weeding and spot replanting during the first few months. Initial plantings of Australian toon should be at a spacing about 6 by 7 feet to 8 by 9 feet—depending on expected survival. Tropical ash should probably be planted at even a closer spacing.

Other practices might be effective in improving planted stands. Since stem forking below 12 feet is a major culling factor, pruning may be a means of achieving a higher number of acceptable or desirable trees. Also, it may be possible to convert cull trees to growing stock through coppice sprouts. Before such practices are carried out on any large scale, their effectiveness should be studied.

## SUMMARY

Wick, Herbert L., Robert E. Nelson, and Libert K. Landgraf

1971. **Australian toon planted in Hawaii: tree quality, growth and stocking.** Berkeley, Calif., Pacific SW. Forest & Range Exp. Sta., 10 p., illus. (USDA Forest Serv. Res. Paper PSW-69)

*Oxford:* 176.1 *Toona australis* (969):232.4.

*Retrieval Terms: Toona australis;* plantation stand establishment; stocking density; soil factors; Hawaii.

Australian toon *(Toona australis)* is used extensively for reforestation in Hawaii. About 250,000 seedlings are planted annually. Even within short distances, seedlings can vary widely in growth rate and form. Criteria for stand improvement can be developed if the trees that likely will be of low quality can be identified early in a stand's life. Such standards would include the number of seedlings to be planted to obtain desired stocking, and the precise guidelines in selecting areas for land clearing and reforestation based on the relationship of tree survival and growth to site factors.

The condition of 5- to 8-yèar-old plantations of Australian toon, toon-tropical ash, and toon-koa on the Waiakea-Olaa reforeststion area, island of Hawaii, was studied to determine (a) levels of stocking and tree growth and quality, and (b) how the levels are related to site factors. The site factors investigated were soil depth, microtopography class, soil drainage class, and kind of parent rocks.

Sample plots were randomly set up in plantings made each year from 1961 to 1965. Each plot was a 1/2-acre strip oriented perpendicular to the general lava flow pattern to intercept a variety of conditions. Data were analyzed to determine levels of stocking (survival of planted trees) and its quality. Each tree was placed in a quality class. The effects of site factors were tested by chi-square techniques.

From records of the Hawaii Division of Forestry we assumed that 436 seedlings had been planted on each acre. Of this initial planting, an average of 274 trees per acre had survived. Stocking in plots of pure

toon averaged 236 trees per acre. In plots of mixed toon-tropical ash, stocking averaged 127 toon trees and 200 tropical ash trees per acre. In plots of mixed toon and koa, it averaged 306 toon trees and 94 koa trees per acre.

Distribution of stocking was significantly affected by soil parent rock, microtopography, soil depth, and soil drainage class. And all of these site factors, except soil depth class, were significantly related to tree quality.

The Australian toon trees were generally of better quality than tropical ash or koa: 31 percent of the toon were classified as desirable trees, and 43 percent as acceptable. Only about 11 percent of the ash and koa trees were rated desirable. Generally, the diameter and height growth of acceptable and desirable trees have been good.

Results of this study suggest that (a) Australian toon or tropical ash should not be planted on areas of pahoehoe, shallow soils on compacted aa, or poorly drained areas; and that (b) about 600 to 1,000 seedlings should be planted on each acre and properly tended, including weeding and spot replanting during the first few months. Initial planting of toon should be at a spacing of about 6 by 7 feet to 8 by 9 feet—depending on expected survival. Other cultural practices may help stand improvement, but they should be studied before being carried out on a large scale.

## APPENDIX: *Tables*

Table 1—*Number of trees per acre on 18 sample plots, by species and quality class Waiakea-Olaa Reforestation Area, island of Hawaii*

| Year planted and plot no. | Total trees/acre | | | | Desirable trees/acre | | | | Acceptable trees/acre | | | | Cull trees/acre | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Toon | Ash | Koa | Total | Toon | Ash | Koa | Total | Toon | Ash | Koa | Total | Toon | Ash | Koa | Total |
| 1961: | | | | | | | | | | | | | | | | |
| 1 | 104 | | | 104 | 14 | - | | 14 | 34 | | - | 34 | 56 | | | 56 |
| 2 | 234 | | | 234 | 22 | | | 22 | 132 | - | | 132 | 80 | | | 80 |
| 3 | 192 | | | 192 | 30 | | | 30 | 96 | | | 96 | 66 | | | 66 |
| 4 | 322 | | | 322 | 24 | - | | 24 | 162 | | - | 162 | 136 | | | 136 |
| 1962: | | | | | | | | | | | | | | | | |
| 5 | 146 | | | 146 | 44 | | | 44 | 44 | - | | 44 | 58 | - | | 58 |
| 6 | 202 | 216 | | 418 | 34 | 4 | | 38 | 112 | 92 | | 204 | 56 | 120 | | 176 |
| 7 | 376 | | | 376 | 108 | | | 108 | 222 | - | - | 222 | 46 | | - | 46 |
| 8 | 354 | | 144 | 498 | 166 | | 22 | 188 | 146 | | 40 | 186 | 42 | | 82 | 124 |
| 1963: | | | | | | | | | | | | | | | | |
| 9 | 66 | 184 | - | 250 | 10 | 14 | | 24 | 34 | 34 | - | 68 | 22 | 136 | | 158 |
| 10 | 258 | | 44 | 302 | 34 | – | | 34 | 136 | | 16 | 152 | 86 | | 30 | 116 |
| 11 | 330 | | | 330 | 162 | | | 162 | 136 | – | | 136 | 32 | | | 32 |
| 12 | 286 | | | 286 | 72 | – | | 72 | 128 | | | 128 | 86 | | - | 86 |
| 1964: | | | | | | | | | | | | | | | | |
| 13 | 98 | 224 | | 322 | 46 | 48 | | 94 | 36 | 56 | – | 92 | 16 | 120 | | 136 |
| 14 | 256 | – | | 256 | 122 | – | | 122 | 88 | | | 88 | 46 | | | 46 |
| 15 | 334 | – | – | 334 | 228 | – | – | 228 | 78 | | | 78 | 28 | | | 28 |
| 16 | 142 | 174 | - | 316 | 30 | 20 | | 50 | 48 | 20 | | 68 | 64 | 134 | – | 198 |
| 1965: | | | | | | | | | | | | | | | | |
| 17 | 158 | | – | 158 | 22 | | | 22 | 40 | | | 40 | 96 | | | 96 |
| 18 | 96 | | | 96 | 56 | – | | 56 | 18 | | – | 18 | 22 | | | 22 |

Table 2—*Sample area and trees observed and expected on sample plots, by site factor class, Waiakea-Olaa Reforestation Area, island of Hawaii*

| Site factor | Sample area in each class | Trees observed | Trees expected |
|---|---|---|---|
| | *Percent* | *No.* | *No.* |
| Microtopography: | | | |
| Level | 36 | 868 | 888 |
| Swale | 6 | 257 | 160 |
| Side slope | 52 | 1,080 | 1,285 |
| Ridge | 6 | 264 | 136 |
| Total | 100 | 2,469 | 2,469 |
| Soil depth (inches): | | | |
| 0-12 | 69 | 1,758 | 1,713 |
| 13-24 | 29 | 627 | 709 |
| 25+ | 2 | 84 | 47 |
| Total | 100 | 2,469 | 2,469 |
| Drainage: | | | |
| Good | 96 | 2,420 | 2,361 |
| Poor | 4 | 49 | 108 |
| Total | 100 | 2,469 | 2,469 |
| Parent rock: | | | |
| aa | 74 | 1,935 | 1,820 |
| Broken pahoehoe | 9 | 253 | 228 |
| Pahoehoe | 17 | 281 | 421 |
| Total | 100 | 2,469 | 2,469 |

Table 3—*Trees observed and expected on sample plots, by microtopography class combined with other site factors, Waiakea-Olaa Reforestation Area, island of Hawaii*

| Micro-topography class | Soil depth | | | Drainage | | | Parent rock | | |
|---|---|---|---|---|---|---|---|---|---|
| | Class | Trees observed | Trees expected | Class | Trees observed | Trees expected | Class[1] | Trees observed | Trees expected |
| | *Inches* | *No.* | | | *No.* | | | *No.* | |
| Level | 0-12 | 661 | 662 | Good | 830 | 807 | 1 | 698 | 650 |
| | 13-24 | 196 | 221 | Poor | 38 | 81 | 2 | 45 | 35 |
| | 25+ | 11 | 5 | | | | 3 | 125 | 203 |
| Total | | 868 | 888 | | 868 | 888 | | 868 | 888 |
| Swale | 0-12 | 170 | 102 | Good | 252 | 154 | 1 | 199 | 119 |
| | 13-24 | 79 | 51 | Poor | 5 | 6 | 2 | 44 | 30 |
| | 25+ | 8 | 7 | | | | 3 | 14 | 11 |
| Total | | 257 | 160 | | 257 | 160 | | 257 | 160 |
| Side slope | 0-12 | 751 | 860 | Good | 1,078 | 1,268 | 1 | 834 | 956 |
| | 13-24 | 281 | 395 | Poor | 2 | 17 | 2 | 136 | 148 |
| | 25+ | 48 | 30 | | | | 3 | 110 | 181 |
| Total | | 1,080 | 1,285 | | 1,080 | 1,285 | | 1,080 | 1,285 |
| Ridge | 0-12 | 176 | 89 | Good | 260 | 132 | 1 | 204 | 95 |
| | 13-24 | 71 | 42 | Poor | 4 | 4 | 2 | 28 | 15 |
| | 25+ | 17 | 5 | | | | 3 | 32 | 26 |
| Total | | 264 | 136 | | 264 | 136 | | 264 | 136 |
| Total | | 2,469 | 2,469 | - | 2,469 | 2,469 | - | 2,469 | 2,469 |

[1]Parent rock class: 1 = aa; 2 = broken pahoehoe; 3 = pahoehoe.

Table 4—*Sample area, trees observed and expected on sample plots, by soil depth class, parent rock and drainage class, Waiakea-Olaa Reforestation Area, island of Hawaii*

| Soil depth class (inches) | Parent rock | | | | Drainage | | | |
|---|---|---|---|---|---|---|---|---|
| | Class | Sample area | Trees observed | Trees expected | Class | Sample area | Trees observed | Trees expected |
| | | *Pct.* | *No.* | | | *Pct.* | *No.* | |
| 0-12 | aa | 52.7 | 1,446 | 1,302 | Good | 66.3 | 1,725 | 1,636 |
| | Broken pahoehoe | 3.2 | 96 | 80 | Poor | 3.1 | 33 | 77 |
| | Pahoehoe | 13.4 | 216 | 331 | | | | |
| 13-24 | aa | 19.9 | 434 | 491 | Good | 27.5 | 611 | 679 |
| | Broken pahoehoe | 5.4 | 131 | 133 | Poor | 1.2 | 16 | 30 |
| | Pahoehoe | 3.5 | 62 | 85 | | | | |
| 25+ | aa | 1.1 | 55 | 27 | Good | 1.9 | 84 | 46 |
| | Broken pahoehoe | .6 | 26 | 15 | Poor | (1) | 0 | 1 |
| | Pahoehoe | .2 | 3 | 5 | | | | |
| Total | | 100.0 | 2,469 | 2,469 | | 100.0 | 2,469 | 2,469 |

[1]Less than 0.1 percent.

Table 5—*Sample area and trees observed and expected, by drainage class and parent rock Waiakea-Olaa Reforestation Area, island of Hawaii*

| Parent rock | Percent of sample area | Trees observed | Trees expected |
|---|---|---|---|
| | | *No.* | |
| GOOD DRAINAGE | | | |
| aa | 73.4 | 1,930 | 1,809 |
| Broken pahoehoe | 9.2 | 250 | 228 |
| Pahoehoe | 13.1 | 240 | 324 |
| POOR DRAINAGE | | | |
| aa | .4 | 5 | 11 |
| Broken pahoehoe | (1) | [2]3 | 0 |
| Pahoehoe | 3.9 | 41 | 97 |
| Total | 100.0 | 2,469 | 2,469 |

[1]Considered less than 0.1 percent.

[2]For all analyses these trees were included in "Good" drainage class.

Table 6—*Cull trees tallied in sample plots, by species and cull factor, Waiakea-Olaa Reforestation Area, island of Hawaii*

| Cull factor | Toon | Ash | Koa |
|---|---|---|---|
| | *Percent* | | |
| Fork below 12 feet | 56 | 81 | 34 |
| Excessive lean | 30 | 13 | 36 |
| Lodging | 6 | 6 | 18 |
| Low vigor; suppressed | 6 | – | 12 |
| Excessive branching | 2 | – | – |
| Total | 100 | 100 | 100 |

Table 7—*Cull trees observed and expected, by site factor class Waiakea-Olaa Reforestation Area, island of Hawaii*

| Class | Trees observed | Trees expected |
|---|---|---|
| | *No.* | |
| Microtophography: | | |
| Level | 270 | 293 |
| Swale | 60 | 86 |
| Side slope | 401 | 363 |
| Ridge | 99 | 88 |
| Total | 830 | 830 |
| Soil depth (inches): | | |
| 0-12 | 585 | 591 |
| 13-24 | 211 | 211 |
| 25+ | 34 | 28 |
| Total | 830 | 830 |
| Drainage: | | |
| Good | 804 | 814 |
| Poor | 26 | 16 |
| Total | 830 | 830 |
| Parent rock: | | |
| aa | 593 | 651 |
| Broken pahoehoe | 80 | 84 |
| Pahoehoe | 157 | 95 |
| Total | 830 | 830 |

Table 8—*Cull trees tallied in sample plots in each microtopography class, by site factor combination, Waiakea-Olaa Reforestation Area, island of Hawaii*

| Micro-topography class | Soil depth | | | Drainage | | | Parent rock | | |
|---|---|---|---|---|---|---|---|---|---|
| | Class | Trees observed | Trees expected | Class | Trees observed | Trees expected | Class[1] | Trees observed | Trees expected |
| | *Inches* | *No.* | | | *No.* | | | *No.* | |
| Level | 0-12 | 204 | 223 | | 249 | 279 | 1 | 180 | 235 |
| | 13-24 | 63 | 66 | Good | 21 | 14 | 2 | 19 | 15 |
| | 25+ | 3 | 4 | Poor | | | 3 | 71 | 43 |
| Total | | 270 | 293 | | 270 | 293 | | 270 | 293 |
| Swale | 0-12 | 33 | 57 | | 58 | 85 | 1 | 44 | 67 |
| | 13-24 | 25 | 26 | Good | 2 | 1 | 2 | 9 | 14 |
| | 25+ | 2 | 3 | Poor | | | 3 | 7 | 5 |
| Total | | 60 | 86 | | 60 | 86 | | 60 | 86 |
| Side slope | 0-12 | 284 | 252 | | 401 | 363 | 1 | 302 | 280 |
| | 13-24 | 99 | 95 | Good | | | 2 | 41 | 46 |
| | 25+ | 18 | 16 | Poor | | | 3 | 58 | 37 |
| Total | | 401 | 363 | | 401 | 363 | | 401 | 363 |
| Ridge | 0-12 | 64 | 59 | | 96 | 87 | 1 | 67 | 69 |
| | 13-24 | 24 | 24 | Good | 3 | 1 | 2 | 11 | 9 |
| | 25+ | 11 | 5 | Poor | | | 3 | 21 | 10 |
| Total | | 99 | 88 | | 99 | 88 | | 99 | 88 |
| Total | | 830 | 830 | | 830 | 830 | | 830 | 830 |

[1]Parent rock class: 1 = aa; 2 = broken pahoehoe; 3 = pahoehoe.

Table 9—*Stocking distribution of desirable and acceptable trees in Australian toon stands, Waiakea-Olaa Reforestation Area, island of Hawaii*

| Plot No. | Quadrats stocked with desirable or acceptable trees | | 1/100-acre quadrats[2] stocked with desirable trees |
|---|---|---|---|
| | 1/400 acre[1] | 1/100 acre[2] | |
| | *Percent* | | |
| 1 | 12 | 35 | 10 |
| 2 | 36 | 81 | 15 |
| 3 | 29 | 68 | 27 |
| 4 | 41 | 85 | 19 |
| 5 | 21 | 63 | 34 |
| 7 | 65 | 98 | 73 |
| 11 | 66 | 100 | 81 |
| 12 | 45 | 90 | 47 |
| 14 | 46 | 87 | 40 |
| 15 | 63 | 95 | 87 |
| 17 | 14 | 48 | 15 |
| 18 | 17 | 52 | 39 |
| Average | 38 | 75 | 41 |

[1]Basis of 378 quadrats systematically located in each transect plot.
[2]Basis of 62 quadrats systematically located in each transect plot.

Table 10—*Average annual diameter and height growth of acceptable and desirable trees in Australian toon stands of different ages, Waiakea-Olaa Reforestation Area, island of Hawaii*

| Stand age (months) | Plot number | Average diameter growth and range | Average height growth and range |
|---|---|---|---|
| | | *Inches per year* | *Feet per year* |
| 92 | 1 | 0.43 (0.10-0.78) | 3.0 (1.9-4.6) |
| 91 | 3 | .41 ( .04-1.18) | 2.8 ( .8-5.3) |
| 90 | 4 | .50 ( .07-1.29) | 3.4 (1.5-5.6) |
| 89 | 2 | .56 ( .19-1.28) | 3.7 (1.8-7.3) |
| 77 | 7 | .58 ( .16-1.33) | 4.2 (1.9-7.9) |
| 76 | 5 | .31 ( .03-0.69) | 2.2 (1.1-4.7) |
| 62 | 11 | .70 ( .12-1.30) | 5.8 (1.9-9.3) |
| 60 | 12 | .76 ( .14-1.70) | 6.0 (1.8-11.4) |
| 59 | 15 | .49 ( .06-1.32) | 4.1 (1.2-9.7) |
| 51 | 14 | .37 ( .02-1.18) | 3.0 (1.2-7.5) |
| 45 | 17 | .61 ( .32-1.20) | 4.6 (2.9-6.6) |
| 45 | 18 | .43 ( .13-1.15) | 3.7 (1.6-8.5) |

GPO 980-964

Wick, Herbert L., Robert E. Nelson, and Libert K. Landgraf

1971. **Australian toon planted in Hawaii: tree quality, growth, and stocking.** Berkeley, Calif., Pacific SW. Forest & Range Exp. Sta. 10 p., illus. (USDA Forest Serv. Res. Paper PSW-69)

Tree quality and rates of growth and survival were higher in 5- to 8-year-old Australian toon *(Toona australis)* plantations on sites with deep soils, good drainage, and aa or broken pahoehoe rock than in plantations on sites with poor drainage or unbroken pahoehoe rock. Stocking averaged 236 trees per acre. Spacing in initial plants should be about 6 by 7 feet to 8 by 9 feet—depending on expected survival. And during the first few months, weeding and replanting should be done.

*Oxford:* 176.1 *Toona australis*(969):232.4.
*Retrieval Terms: Toona australis;* plantation stand establishment; stocking density; soil factors; Hawaii.

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PACIFIC SOUTHWEST
Forest and Range
Experiment Station

EST SERVICE
DEPARTMENT OF AGRICULTURE
BOX 245, BERKELEY, CALIFORNIA 94701

# Timber RAM... a long-range planning method for commercial timber lands under multiple-use management

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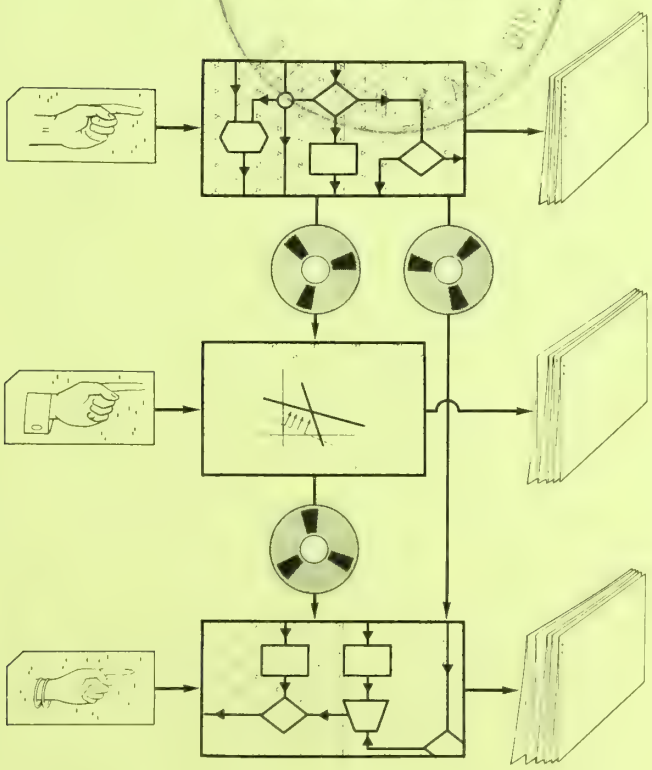
Daniel I. Navon



USDA FOREST SERVICE RESEARCH PAPER PSW- 70 /1971

# FOREWORD

A major aim of the Multiple-Use Economics research unit of the Pacific Southwest Forest and Range Experiment Station is the development of a Resources Allocation Method (RAM). This method is designed to provide an analytical framework for drawing long-range forest management plans and for evaluating wildland multiple-use management policies.

Timber RAM is a subsystem of RAM, designed to generate cutting and reforestation schedules for commercial forest lands under multiple-use management. These Timber RAM plans can be used to evaluate current management policies and goals and to evolve new ones. Timber RAM was developed by the following members of the research unit staff:

Daniel I. Navon, *Economist*
Michael J. Irving, *Mathematician and Programer* (part-time)
LeRoy C. Hennes, *Forester* (part-time)
Narendra S. Bakshi, *Systems Analyst* (part-time)
Steven Chen, *Computer Scientist* (part-time)

Special credit is due Michael Irving and Steven Chen for writing the Timbram-Matrix program and Michael Irving for writing the Timbram-Report program.

Valuable assistance in the testing of Timber RAM was provided by the Branch of Management Plans and Timber Inventories, California Region of the Forest Service, U.S. Department of Agriculture, San Francisco, California.

The Timber Resources Allocation Method (Timber RAM) is a computerized method for developing long-range forest management plans. Each Timber RAM plan consists of a cutting and reforestation schedule and of reports tabulating the corresponding stumpage volumes, revenues, and costs. Schedules and reports can span a sequence of decades extending from the present to a "planning horizon" up to 35 decades in the future. With Timber RAM plans, the stumpage and economic potential of large forested areas can be estimated for alternative management policies. Timber RAM plans can also provide aggregate input and output goals and management guidelines for sequences of annual plans. The schedule and corresponding stumpage volumes, revenues, and costs of Timber RAM plans are calculated for 10-year periods. They can also be calculated separately for the first half and for the second half of the first decade to provide schedules and reports for 5-year plans.

Given an inventory of forest resources and alternative ways of managing each type of stand, Timber RAM can be used to calculate a schedule which meets a specified objective, such as: maximize revenues, maximize stumpage volume harvested, or minimize expenditures. Besides meeting the objective, the Timber RAM schedule can be required to meet constraints on the periodic level of revenues, and expenditures, and on the periodic volume of stumpage harvested. The levels at which revenues, expenditures and stumpage are constrained can be varied from period to period. Finally, the Timber RAM schedule can be required to meet constraints specifying what percentage of each type of stand will become accessible for cutting in successive periods.

Timber RAM can be used to develop long-range plans for both privately and publicly owned forests. Private owners, for example, may choose for the objective: maximize the present value of net revenue. They may also choose to constrain cash flows and stumpage harvested above minimum levels for two or three decades. Private owners with an interest in conservation may want to assure a minimum supply of stumpage for additional decades. Private owners with heirs, and public agencies, may well feel obliged to assure a perpetual and stable supply of stumpage. With Timber RAM, they can develop such plans by constraining harvest levels for as long as 35 decades—ample time to stabilize the periodic yield of any forest. Some public agencies may prefer to specify the objective: minimize expenditures; and constrain timber harvest above minimum levels for one or two rotations to insure a sustained yield of stumpage. Public agencies may also want to constrain revenues above a minimum level for several decades to meet the needs of local government.

The opportunity costs of imposing such constraints can be estimated by calculating a second plan in which the constraints have been deleted or modified. An opportunity cost is defined as the difference in the value of the objective in the two plans. The opportunity costs of a policy requiring a stable and perpetual supply of stumpage can be estimated by calculating two Timber RAM plans; the first in which periodic stumpage harvests are constrained for, say two rotations, and the second in which periodic stumpage harvests are not constrained, or constrained for only two or three decades. The opportunity cost of other multiple-use management policies can be estimated in the same way; for example, the opportunity cost of establishing stream bank protection zone of various widths, or of extending endangered species habitats.

Maximizing revenues—or minimizing expenditures—is only one of the goals of forest management. By specifying constraints it is possible to introduce explicitly into the planning process many of the other goals pursued by private owners and public agencies.

This paper describes the Timber RAM approach to long-range forest management planning. It outlines the procedures for using Timber RAM on computers, and explains the options of the computer programs.

Timber RAM plans are calculated by the linear programing method. This method has been completely automated and linear programing codes are available commercially for every large and medium size computer. The current version of Timber RAM requires the use of the linear programing code ILONA on the UNIVAC 1108 computer. The Timber RAM programs can be easily adapted to other combinations of linear programing code and computer. The California Region, U.S. Forest Service, for example, is

adapting the Timber RAM programs to the code REX and the CDC 3100 computer.

The Timber RAM computer programs and a four-part Users' Manual are available on request to the Director, Pacific Southwest Forest and Range Experiment Station, P.O. Box 245, Berkeley, California 94701. Each program listing and each part of the Users' Manual must be requested by title. To obtain a copy of the programs on magnetic tape, send a 7-track, 800 BPI, one-half-inch tape at least 1,200 feet long to the Director, Attention: Computer Sciences Library. This tape will be written in UNIVAC 1108 EXEC II Symbolic CUR format unless card image format is requested.

Part I of the Users' Manual is the *Smokey Forest Case Study*. It illustrates the use of Timber RAM to draw long-range plans for the Smokey Forest, a hypothetical publicly owned forest. The data forms and listings of the control decks necessary to make the computer runs discussed in the case study are available on specific request to the Director.

Part II of the Users' Manual is the *Forester's Guide*. With this Guide, professional foresters without training in linear programing can use all the standard Timber RAM options. But if they are completely unfamiliar with the care and feeding of computers, they will require some help to process Timber RAM computer runs.

Part III is the *Mathematical Programer's Guide*. It describes the mathematical relations used in Timber RAM. If Timber RAM is used extensively, some savings in data processing can be realized with procedures discussed in this guide. Familiarity with the theory of linear programing and experience in using computers are prerequisites to using these procedures.

Part IV is the *Computer Programer's Guide*. It includes a description and a flow chart of every subroutine used in the Timber RAM programs. The Computer Programer's Guide is primarily designed to facilitate the adaptation of the Timber RAM programs to any large or medium size computer, and to their linear programing codes.

A wide spectrum of silvicultural treatments and management policies can be analyzed with the standard options of Timber RAM. This spectrum can be further broadened by minor modifications in the Timber RAM programs. The necessary information for modifying these programs is presented in the Computer Programer's and the Mathematical Programer's Guides.

# TIMBER RAM APPROACH

## *Timber RAM Activities*

The Timber RAM approach involves the selection of a combination of "activities" maximizing—or minimizing—an objective and satisfying constraints. Each activity is a complete sequence of silvicultural treatments extending from the present to the planning horizon. To minimize data processing, all timber stands with similar silvicultural and economic characteristics are grouped into a "timber class." Several activities are then defined for each timber class. A typical activity for a timber class consisting of overaged stands on highly productive land might consist of the following sequence: (1) clearcut the standing timber and plant in the first decade; (2) partial cut the regenerated timber on a 10-year cycle from the sixth decade until the harvest cut in the ninth decade; (3) repeat the treatments on the regenerated timber up to the planning horizon. The Timber RAM activities are expressed by the total inputs per acre required and the total outputs per acre produced in each decade. The concept of an activity can be easily grasped from illustrations for a simplified problem with a 10-decade planning horizon in which stumpage and net revenue are the outputs and land the only input *(fig. 1)*. Activity 1 is the Timber RAM activity for the sequence of treatments described above. Stumpage is expressed here in thousands of board feet (MBF) and net revenue in dollars. Outputs and inputs are listed for each decade—with one exception: land. Since this input is the same for every decade (1 acre) it is listed only once. Activity 2 and activity 3 represent the same sequence of treatments as activity 1 but with the standing timber harvest scheduled in decade 2 and 3. Additional activities must be specified if this overaged stand is to be carried beyond the third decade. Activities 1, 2, and 3 assume an 8-decade rotation age for the regenerated timber. To evaluate alternative rotation ages, additional activities must be specified. Activities 4, 5, and 6 represent the same sequence of treatments as the first three activities but with a 7-decade rotation age for the regenerated timber *(fig. 1)*. Any sequence of treatments can be described by a Timber RAM activity. Precommercial thinning of

| Decade | Inputs and Outputs | ACTIVITIES (80-year rotation) | | | ACTIVITIES (70-year rotation) | | | ACTIVITIES (70-year rotation) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1st | Vol.<br>Net Rev.<br>(disc.) | 35<br>700<br>(523) | | | 35<br>700<br>(523) | | | | 12<br>240<br>(179) | 12<br>240<br>(179) |
| 2nd | Vol.<br>Net Rev.<br>(disc.) | | 36<br>720<br>(300) | | | 36<br>720<br>(300) | | | | 5<br>100<br>(42) |
| 3rd | Vol.<br>Net Rev.<br>(disc.) | | | 34<br>680<br>(158) | | | 34<br>680<br>(158) | 34<br>680<br>(158) | 28<br>560<br>(130) | 26<br>520<br>(121) |
| 4th | Vol.<br>Net Rev.<br>(disc.) | | | | | | | | | |
| 5th | Vol.<br>Net Rev.<br>(disc.) | | | | | | | 0<br>-55<br>(-4) | | |
| 6th | Vol.<br>Net Rev.<br>(disc.) | 5<br>75<br>(3) | | | 5<br>75<br>(3) | | | | | |
| 7th | Vol.<br>Net Rev.<br>(disc.) | 8<br>120<br>(3) | 5<br>75<br>(2) | | 6<br>90<br>(2) | 5<br>75<br>(2) | | | | |
| 8th | Vol.<br>Net Rev.<br>(disc.) | 6<br>90<br>(1) | 8<br>120<br>(2) | 5<br>75<br>(1) | 30<br>750<br>(10) | 6<br>90<br>(1) | 5<br>75<br>(1) | 7<br>105<br>(1.4) | 5<br>75<br>(1) | 5<br>75<br>(1) |
| 9th | Vol.<br>Net Rev.<br>(disc.) | 30<br>750<br>(5) | 6<br>90<br>(1) | 8<br>120<br>(1) | | 30<br>750<br>(5) | 6<br>90<br>(1) | 8<br>120<br>(1.3) | 6<br>90<br>(1) | 6<br>90<br>(1) |
| 10th | Vol.<br>Net Rev.<br>(disc.) | | 30<br>750<br>(3) | 6<br>90<br>(.4) | | | 30<br>750<br>(3) | 33<br>825<br>(3.3) | 30<br>750<br>(3) | 30<br>750<br>(3) |
| | Land | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| OBJECTIVE | | 530 | 304 | 159 | 538 | 303 | 159 | 155 | 310 | 301 |

Volume in MBF--Net Revenue in $ (discounted at 6%)--Land in acres

Figure 1—*Timber RAM activities corresponding to sequences of forest treatments defined by periodic outputs (volume harvested and discounted net revenues) and one input (land). The bottom row shows the contribution of each activity to the objective "maximize discounted net revenue over the first eight decades."*

regenerated timber in the fifth decade is illustrated with activity 7; overstory removal in the first decade with activity 8; partial cutting the standing timber in the second decade after an overstory removal in the first decade is illustrated with activity 9. Note that activities specified for a given timber class can represent different sequences of treatments and also different schedulings of the same sequence of treatments.

With the Timber RAM computer program Timbram-Matrix a large number of activities can be specified easily and cheaply, for each timber class,

once timber yield, cost and revenue tables have been prepared.

### Linear Programing

The combination of activities making up a Timber RAM plan, is found by the linear programing method. If no constraints were specified the combination of activities maximizing revenues, maximizing stumpage harvested, or minimizing expenditures could be found by inspection.

To illustrate this point, consider a forest consisting of a single 1,000-acre timber class of over-mature even-aged timber. Let the objective be: to maximize total net revenue from stumpage harvested in the first 8 decades; and let us consider only the sequences of treatment represented by the first six activities defined above *(fig. 1)*. For each activity, let us calculate the total discounted net revenue over the first 8 decades and enter it in the row labeled: objective *(fig. 1)*. Since activity 4 will yield the highest discounted net revenue per acre over the first 8 decades, all 1,000 acres must be managed with activity 4 to maximize the objective.

If because of contractual commitments, a minimum stumpage volume of 10 MMBF must be harvested in each of the first 3 decades, the entire forest cannot be managed with activity 4 since there would be no timber left to harvest in the second and third decade. Now, the combination of activities maximizing the objective and meeting the constraints on stumpage harvested cannot be found by inspection. Although in this example the combination of activities is quickly found with simple arithmetic, more realistic problems involving several timber classes and additional constraints require the use of the linear programing method.

The solution to our simplified problem is: Objective = \$361,522 = (428) (\$538) + (278) (\$304) + (294) (\$159).

| *Activity No.* | *Acres managed* | *Stumpage harvested in decade* | | |
|---|---|---|---|---|
| | | *1st* | *2nd* | *3rd* |
| | | *MMBF* | | |
| 4 | 428 | 15 | 0 | 0 |
| 2 | 278 | 0 | 10 | 0 |
| 6 | 294 | 0 | 0 | 10 |
| Total | 1,000 | 15 | 10 | 10 |

The solution to this problem shows two characteristics typical of Timber RAM plans:

First, the total inputs and outputs contributed by each activity is directly proportional to the number of acres managed with this activity. Mathematicians call this type of proportionality "linearity;" hence, linear programing. For example, the total contribution of activity 4 to the volume harvested in the first decade (15 MMBF), is the yield per acre (35 MBF) multiplied by 428, the number of acres to be managed with this activity. The objective is calculated by the same method.

Second, a given timber class is managed with several activities. In this example 42.8 percent of the timber class area must be managed with activity 4; 27.8 percent with activity 2 and 29.4 percent with activity 6. In real situations there will be many timber classes, nevertheless several activities will typically be required to manage each timber class. These activities may represent different sequences of treatments as well as different schedulings of the same sequence of treatments. Note that, the regenerated timber on the timber class in our problem is managed partly on one rotation (8 decades for activity 2) and partly on another (7 decades for activities 4 and 6).

## PLANNING WITH TIMBER RAM

### Defining Planning Alternatives

With Timber RAM a combination of activities maximizing—or minimizing—an objective is found given a set of activities for each timber class, and constraints on the inputs and outputs. Changing the objective, constraints, or activities defines a new planning alternative for which a different combination of activities will normally be found. For example, given a set of activities and constraints, a combination of activities will be obtained by selecting as objective: the total discounted net revenue collected over 8 decades; a different combination of activities will be obtained in most situations if instead, total discounted net revenue collected over 4 decades is selected as the objective. Each new combination of activities is also a new Timber RAM plan.

Several Timber RAM plans will normally be required to plan each management unit. The first Timber RAM plan can reflect current or tentative policies and goals. For example: maximize discounted net revenues for the first 8 decades; clearcut the standing timber and manage the regenerated timber

on a 7- or 8-decade rotation; and harvest at least 10 million board feet in each of the first three decades. This first Timber RAM plan will establish whether the harvest goals for the first 3 decades is feasible, and if it is, what the maximum total discounted net revenue for the first 8 decades can be. A great deal more information is provided by the Timber RAM plan. This information is presented in cutting and reforestation schedules and reports and a Harvest Graph. The schedules display for each activity selected the inputs per acre and outputs per acre; the number of acres to be managed; and the total periodic inputs and outputs. The reports summarize this information for each period over all the activities selected. The Harvest Graph displays the total periodic stumpage harvested for each decade from the present to the planning horizon.

Additional planning alternatives can be defined and the corresponding Timber RAM plans obtained by making one or a combination of changes in the specification of: the objective, the constraints, and the activities. For example: Changes in the objective can be specified:

- by varying the number of decades over which the objective is defined (maximize discounted net revenues over 4 decades instead of over 8 decades)
- by changing the index of performance (maximize stumpage volume harvested, instead of maximize discounted net revenues)
- by varying the discount rate of the index of performance (discount net revenues at 10 instead of 6 percent).

Changes in constraints can be specified by varying the level of constraints in the first Timber RAM plan or by adding or deleting constraints. With such changes it becomes possible:

- to explore changes in current or tentative goals
- to evaluate alternative multiple-use management policies on: even flow, sustained yield, and the size of stream side zones, and of scenic areas and protected wildlife habitats
- to evaluate accelerated road construction or tree improvement programs.

Changes in activities can be specified by adding or deleting activities to evaluate:

- special treatments for sensitive areas
- different rotation ages
- new types of logging
- various levels of management intensity including fertilization and the introduction of genetically improved stock.

Professional training, experience, and intuition must be exercised in selecting the specifications of each additional planning alternative.

## Generating Timber RAM Plans

To generate Timber RAM plans three steps are required *(fig. 2).* Each step consists of preparing an input deck and making a computer run.

Step I: setting up a Timber RAM problem with the program Timbram-Matrix. Objectives, constraints, and all the data necessary to define activities for every timber class are entered on specially designed data forms. The Data Input deck for step I is punched directly from these forms. The program Timbram-Matrix is then run to produce the Linear Program (LP) Data Input Tape used in step II and the Report Input Tape used in step III. The information printed on these tapes can be checked by inspecting the Timbram-Matrix Input computer printout. Errors are eliminated by correcting the data input deck and re-running Timbram-Matrix.

Step II: Finding a combination of activities with the linear programing computer code ILONA *(fig. 2).* The LP Control deck consists of only a few cards used to select particular options of the computer program ILONA and to specify which objective of the Timber RAM problem will be maximized–or minimized. Changes in the level of periodic harvest, revenue and cost constraints can also be made with the LP Control deck. Except for experienced mathematical programers, changes in the other constraints or in the activities require repeating step I to set up another Timber RAM problem. (Procedures for changing, adding, or deleting every constraint and activity with the LP Controls are described in the *Mathematical Programer's Guide.*) With a single Timber RAM problem it is therefore possible to define many planning alternatives and to generate the corresponding Timber RAM plans.

The computer run with the program ILONA has two possible outcomes, depending on whether there exists a combination of activities which satisfies the constraints specified. If a combination exists, ILONA will find it and prepare the Linear Program Solution Tape used in step III. If no combination of activities can satisfy all the constraints, ILONA will abort with the comment: "infeasible." In either case, the LP Iteration Log and Solution computer printout provides detailed information on the calculations performed by ILONA. In case of infeasibility, the constraint or constraints causing the infeasibility can be detected and modified or removed by trial and error methods.

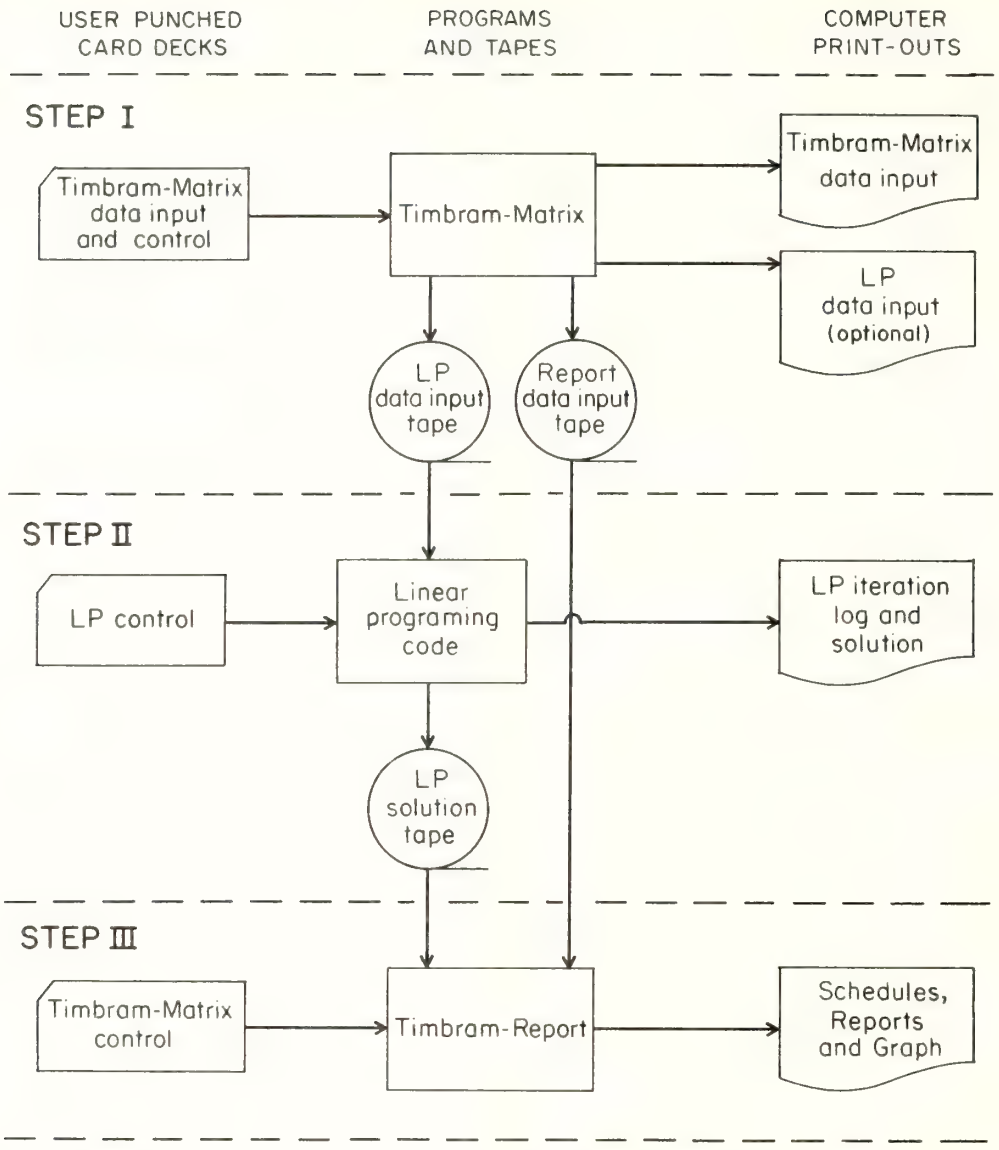



Figure 2—*Three steps are required to generate a Timber RAM plan. Step I: set up a Timber RAM problem with the program Timbram-Matrix. Step II: find a combination of activities with the linear programing computer code ILONA. Step III: translate the combination of activities into Schedules, Reports, and a Graph with the computer program Timbram-Report.*

Step III: translating the combination of activities into schedules and reports and a harvest graph with the Timber RAM program Timbram-Report *(fig. 2)*. The Timbram-Report Control deck consists of only a few cards specifying which documents are desired, the number of periods to be covered by each document, and the rates to be used in discounting revenues and costs.

The three Timber RAM steps can be performed in a single integrated computer run. However, this should not be attempted until the data have been meticulously checked and the user has acquired some experience in running these programs.

The cost of generating Timber RAM plans vary greatly with the specifications of the Timber RAM problem, the LP code, and the computer used. Generally, costs can be expected to rise steeply as the number of timber classes and decades is increased;

but the cost of each subsequent Timber RAM plan will often be only a fraction of the cost of the initial plan.

## Selecting a Timber RAM Plan

If all the inputs and outputs defining the activities can be expressed in some common unit, a single value for each Timber RAM plan can be calculated. Then Timber RAM plans can be ranked rationally. If no common unit can be defined, the alternative solutions must be ranked intuitively. Even if a purely rational ranking of plans is possible, the final selection of a plan must be made intuitively to give proper consideration to social needs and political realities.

In the process of selecting a plan, management policies represented by alternative Timber RAM plans are implicitly evaluated. An explicit evaluation can be made once a plan has been selected, by changing the specifications of the constraints or of the activities to simulate the change in policy to be evaluated. The coordination of resource management planning with road construction planning can also be carried out by changing the specification of constraints. For example, the management of stands in unroaded areas might be planned as follows:

A Timber RAM plan is generated on the assumptions all stands are currently accessible. This plan is submitted to the transportation planners who determine whether an economical roading plan can be developed to meet the requirements of this initial Timber RAM plan. Transportation planners may find it economical to defer road access to certain stands. Accessibility constraints would be specified and a new Timber RAM plan generated. This plan would again be submitted to the transportation planners for review. This procedure can be extended to include review of Timber RAM plans or revisions of Timber RAM problems by fire, recreation, range and wildlife management planners.

When linear programing is used to find a combination of activities, the assumption is made that for each activity, average timber yield, costs, and revenues per acre are constant regardless of the number of acres managed with this activity. When timber classes are reasonably homogeneous, the average stumpage harvested with any activity is indeed constant—regardless of the number of acres cut; average revenues and costs, however, ususally are not. If large areas are cut, the average revenue per acre may fall as the price is driven down; so will the average cost per acre as economies of scale are realized.

This proportionality—or linearity—assumption introduces a possible bias in the estimation of total periodic inputs and outputs and in the selection of the combination of activities. The economic data used in long range planning are necessarily crude: expected prices and costs 10, 20, 30 years hence, often for treatments never yet attempted. The additional error induced by the "linearity" assumption will be relatively small if for each activity, average costs and revenues per acre are estimated for an "expected number of acres managed," equal to, say, one-half the acreage of the timber class. The activity level for each Timber RAM plan must then be inspected to establish by how much they differ from the "expected number of acres managed," and to determine whether the inputs and outputs per acre defining the activities are still acceptable estimates.

To obtain a more rigorous measure of the possible bias introduced by the "linearity" assumption, the objective and total periodic inputs and outputs of the Timber RAM plan can be recalculated with adjusted inputs and outputs for the activities selected by the linear program. This step requires making only two computer runs: one with Timbram-Matrix and one with Timbram-Report. (Detailed procedures are explained in the *Forester's Guide*—Part II of the Users' Manual.) The schedules and reports obtained without making a linear programing computer run are only a pseudo Timber RAM plan because by definition a Timber RAM plan is a solution to a linear programing run.

If the differences between the Timber RAM plan and the pseudo Timber RAM plan are unacceptably large, a new Timber RAM plan can be generated with the adjusted coefficients, and the activity levels once more inspected. By comparing the schedule of the initial Timber RAM plan with that of the Timber RAM plan generated with adjusted costs and revenues the bias induced by the linearity assumptions in the selection of the combination of activities can be assessed.

The stability of the combination of activities, objectives, and total periodic inputs and outputs with respect to adjustments in the data, must in any case be explored before making operational decisions based on Timber RAM plans. If a 10 percent change in costs, revenues, or stumpage data results in a combination of activities requiring completely different treatments or schedulings of treatments, then the Timber RAM plans cannot provide stable management guidelines. However, they may still provide stable estimates of the economic and silviculture potential of a forest. For example, the Timber RAM

plan based on adjusted inputs and outputs may require that a completely different group of timber classes be managed intensively but show only small changes in the objective and total periodic inputs and outputs. Fortunately, the stability of Timber RAM plans can, in many cases, be improved by redefining some of the timber classes and activities.[1] Of course, only the individuals responsible for making management decisions can judge what level of instability in the Timber RAM plans is acceptable. If acceptably stable plans cannot be generated with Timber RAM, more sophisticated methods, such as, quadratic, dynamic or mixed integer linear programing must be used to develop long-range plans.

The realism with which land management and policy alternatives can be evaluated with Timber RAM plans depends on the characteristics of the Timber Resources Allocation Method and upon the imagination with which it is used. The characteristics of the method are defined by the aspects of linear programing discussed above and the imagination with which it can be used is restricted by the options of the two Timber RAM programs: Timbram-Matrix and Timbram-Report.

# TIMBRAM-MATRIX OPTIONS

## *Activities*

Timber RAM activities can be defined by two inputs: Land and Cost; and four outputs: Volume Harvested, Gross Revenue 1, Gross Revenue 2, and Net Revenue. Every activity in a Timber RAM problem must be defined by the same inputs and outputs. Any combination of inputs and outputs is admissible as long as it includes land.

The precise definitions of Cost, Gross Revenue 1 and Gross Revenue 2 are left to the discretion of the user. Net Revenue is calculated automatically by Timbram-Matrix as the difference between Gross Revenue 2 and Cost.

Definitions may reflect business or social accounting categories. For example, a public agency might define Cost as operating expenses, Gross Revenue 1 as gross national product, and Gross Revenue 2 as gross stumpage fees collected. Net Revenue which is automatically calculated by Timbram-Matrix as the difference between Gross Revenue 2 (stumpage collected) and Cost (operating expenses) would then represent net revenues.

The units for land, stumpage volume and revenues and costs are respectively acres, thousand board feet and dollars. These can be changed to any unit desired with trivially simple changes in a few subroutines of Timbram-Matrix and Timbram-Report.

The unit of time or period in Timber RAM is a decade. Hence, the inputs and outputs defining the activities are totals over each decade. To provide targets and management guidelines for 5-year plans, inputs and outputs can also be totalled for the first and second half of the first decade. Changing the unit of time requires major modification of several subroutines.

Each input and output can be defined for up to 35 decades. All inputs and outputs need not be defined for the same number of decades, but any one input or output must be defined for the same number of decades in all the activities. To illustrate, for every activity, Volume Harvested can be defined for 30 decades while Revenues and Costs are defined only for 5 decades.

The number of activities which can be defined for each timber class is unlimited. Several hundred activities are likely to be defined for a Timber RAM problem. The data preparation and processing task is greatly reduced with the management alternative options. For each timber class, sequences of treatments are specified and Timbram-Matrix generates the activities corresponding to specified alternative schedulings. For example, activities 1, 2, and 3 discussed above *(fig. 1)* can be generated by defining the management alternative:

- clearcut the standing timber
- reforest the same decade
- partial cut the regenerated timber on a 10-year cycle from age 50 until harvest cut at age 80
- schedule the standing timber cut for the first 3 decades

and by providing Timbram-Matrix with tables of yields, costs, and revenues. To define a management alternative both a sequence of treatments and its scheduling must be specified. This is done by completing a single line on one of the specially designed Timbram-Matrix data forms. Many different types and sequences of treatments can be specified with the

[1]The clues necessary to carry out this delicate task are obtained by making a "sensitivity analysis." See Dantzig, George B., *Linear programming and extensions.* Princeton: Princeton University Press, p. 265-275. 1963.

standard management alternative options. If some activities cannot be specified with these options the user has two alternatives: generate each of these activities himself and enter the data on another of the Timbram-Matrix data forms, or modify the program Timbram-Matrix. The management alternative options and the technique used by Timbram-Matrix to generate activities are discussed in detail in the *Appendix*.

## Objectives

In Timber RAM, each of these inputs and outputs can be used as an index of performance, or objective: Volume Harvested, Gross Revenue 1, Gross Revenue 2, Cost, and Net Revenue. The precise definition of the first four is entirely at the discretion of the user; the last, Net Revenue, is calculated by Timber RAM as the difference between "Gross Revenue 2" and "Cost."

These objectives can be defined for any sequence of decades desired up to the planning horizon of the Timber RAM problem. For example, decisions to "maximize total Net Revenues for the first 3, 5, or 12 decades" represent three possible objectives for a Timber RAM problem with a planning horizon of at least 12 decades. The economic objectives—Gross Revenue 1 and 2, Net Revenue, and Cost—can be discounted at any interest rate desired. In addition, Gross Revenue 1 or 2 and Cost can be discounted at different interest rates—a practice strongly recommended by some economists.[2] But when this is done, no discount rate can be attributed to Net Revenue. All discounting is calculated on the assumption that costs and revenues occur in the middle of each period.

For a given Timber RAM problem six alternative horizons can be specified for each objective. In addition, the cost and revenue objectives can be discounted at seven different interest rates. Up to 174 alternative objectives can be specified in a single Timber RAM problem.

## Constraints

A forest manager's freedom of action is limited by many considerations. Some of these limitations can be expressed in Timber RAM by specifying "Constraints." Thus, the manager can allow for limitations on the area and accessibility of the timber classes; on the availability of genetically improved planting stock; on the periodic level of harvests, costs, and revenues. Constraints can also be specified to regulate the forest and to insure a controlled flow of timber during the conversion period. All these constraints are imposed by specifying upper or lower bounds on the periodic level of the inputs and outputs defining the activities.

### Area and Accessibility Constraints

These constraints are specified individually for each timber class. They can be modified only by making a computer run with Timbram-Matrix to define a new Timber RAM problem.

Area constraints can be specified as the *maximum* number of acres to be managed with the Timber RAM activities; this specification allows the possibility that none, or only a few of the acres of a timber class will be managed. Area constraints can alternatively be specified as the *total* number of acres to be managed with the activities; thus insuring that every acre of this timber class will be managed.

Timber-class area constraints can provide a partial basis for evaluating land classification policies. For example, the impact of establishing scenic corridors or vistas on costs, revenues, and volume harvested can be estimated by reducing the area of the timber classes affected and preparing a new Timber RAM plan. Or the acreage of each timber class falling in the scenic zone can be defined as one or several separate timber classes and special silvicultural treatments specified to preserve the esthetic qualities of this area. The policy to establish scenic zones can then be evaluated by analyzing the schedules and reports for the "scenic" and "nonscenic" Timber RAM plans. This procedure can be extended to evaluate policies on streamside zones, or high-erosion zones.

Accessibility constraints specify the percent of the acreage of each timber class which is expected to be accessible in each of the first five planning periods. These constraints are omitted when every timber class is fully accessible at the beginning of the first period. Note that if the first decade is split into two planning periods, the first five planning periods will span only 4 decades. By manipulating these accessibility constraints, an accelerated road construction plan can be evaluated in terms of the input or output selected as the objective. To do this a second Timber RAM problem is defined—identical to the first except for the percentage of the acres of each timber class

[2]Mobasheri, F. *Optimization techniques in the planning, design, and operation of water resources systems.* (Unpubl. rep. on file, Eng. & Physical Sci. Ext., Univ. Calif., Los Angeles, Calif. 1968.)

accessible in the first five periods, which now must reflect the accelerated roading plan. A first approximation to the value of the accelerated roading plan can be obtained by weighing the change in the objective against the difference in cost of the two roading programs.

### Periodic Constraints

In Timber RAM every constraint is in fact a periodic constraint, but it is convenient to reserve this term for constraints which can be modified without rerunning Timbram-Matrix.

Periodic constraints can be specified on the area planted with genetically improved stock and on the level of each of the five inputs and outputs which can be used as indices of performance (Volume, Gross Revenue 1, Gross Revenue 2, Net Revenue, and Costs). These constraints are specified either by an "upper" or by a "lower" bound on the periodic level. Gross Revenues, Net Revenues, and Volume Harvested can only be constrained above minimum periodic levels by "lower bounds." Costs and the area planted with genetically improved stock, can only be constrained below maximum periodic levels by "upper" bounds. Periodic constraints can be specified for every decade up to the planning horizon. These constraints must be specified with great care since it is quite easy to specify a maximum cost level inconsistent with a minimum harvest or revenue level. In such a case, the linear program computer run will abort and the computer printout will state that there is no feasible solution. Fortunately, these levels can be changed without rerunning the Timbram-Matrix program.

In the first decades of a tree improvement program, the number of acres which can be reforested with the improved stock may be limited by the availability of planting stock. In such a situation, the maximum number of acres on which improved stock can be planted can be specified for every decade up to the planning horizon. In each decade, the improved stock will be allocated to the area offering the highest return—in terms of the objective specified—and normal stock will be planted on the remainder of the acres reforested in that decade. Hence no matter how little genetically improved stock is available, the linear program computer run will never abort because of the constraints.

### Harvest Control and Regulation Constraints

Harvest control constraints are used to shape the stream of harvests, regulation constraints to stabilize it.[3] Control and regulation constraints are specified by an upper and a lower bound on the periodic harvest levels and can be changed only by rerunning Timbram-Matrix. These bounds can be set at different levels for every period. Any degree of control and regulation can be specified by varying the bounds. Harvest control constraints are mandatory. They are imposed on the first and succeeding decades which are then referred to as the "conversion period." Therefore the length of the "conversion period" in Timber RAM is determined by the number of decades for which the user specifies harvest control constraints. The compulsory specification of a "conversion period" greatly simplified the structure of the computer program. Users not interested in harvest control can specify very wide bounds for a single decade. This one decade "conversion period" will have no impact on the selection of combination of activities. Regulation constraints are optional. When they are specified they must be imposed on the remaining decades of the Timber RAM plan which are then referred to as the post-conversion period. Hence in Timber RAM, the post-conversion period always spans the decades from the end of the conversion period to the planning horizon.

Harvest control and regulation constraints can be imposed either on the total stumpage volume or on the total number of acres harvested in each period. In a given Timber RAM problem all the harvests constraints—including the Periodic Harvest constraints—must be expressed in the same units. The constraints being very similar for the "volume" and "area" options, the discussion will assume that periodic harvests are expressed in thousand board feet, and only differences will be pointed out.

Three types of control can be imposed on the conversion-period harvests: arbitrary, sequential and conventional.

In *arbitrary control*, the harvest level of each period is restricted to a range of values specified by a fixed upper and lower bound; for example: 125 and 90 million board feet—or 3,000 and 2,500 acres *(fig. 3A)*. When the arbitrary control and the volume options are selected, Periodic Harvest constraints are redundant and should not be specified. Arbitrary control can be used to generate Timber RAM plans with any sequence of periodic harvests consistent with the resources available and treatments specified.

[3]For a detailed discussion of the Timber RAM approach to forest regulation see Hennes, LeRoy C., Daniel I. Navon, and Michael J. Irving, *Harvest control and regulation in Timber RAM.* USDA Forest Serv. Res. Note PSW-231, 10 p., illus., Pacific SW. Forest & Range Exp. Sta., Berkeley, Calif. 1971.

In *sequential control,* each periodic harvest level is restricted to a range of values around the preceding periodic harvest level *(fig. 3B).* The upper and lower bounds of this range are expressed as a percentage of the preceding periodic harvest level; for example: given a harvest level of 100 million board feet, 0.25 and 0.10 specify the range 125 to 90 million board feet for the next periodic harvest. The first periodic harvest level is restricted to a range around a specified "current level," to provide a means of insuring a smooth transition into the Timber RAM plan. With sequential control constraints, large jumps or drops in stumpage harvested can be bridged by gradual changes in periodic harvest levels.

In *conventional control,* each periodic harvest level is restricted to a range of values around their average *(fig. 3C).* The upper and lower bounds of the range are specified as percentages of the average. The first periodic harvest can in addition be restricted to a range around a specified "current level" to insure a smooth transition into the Timber RAM plan. The upper and lower bounds of this range are also specified as percentages—but of the "current level." (If the two ranges constraining the first periodic harvest are inconsistent, the linear program computer run will abort with the comment "infeasible.")

Regulation constraints are specified to stabilize the periodic stumpage harvest level by redistributing acres among age classes. This is accomplished indirectly by controlling the periodic harvest level after all over-aged or poorly stocked timber classes have been liquidated during the decades of the conversion period. This control is exercized by restricting each of the post conversion periodic harvest levels to a range around their average. The width of this range will reflect the degree of regulation desired.

To illustrate, consider a forest consisting of a dozen timber classes varying with respect to age stocking and area, but of uniform potential productivity or "site class." Let us further assume that all the standing timber is cut during an 8-decade conversion period. If all the regenerated timber is to be managed on the same rotation age, say 80 years, the periodic harvests after the eighth decade will re-occur on an 8-decade "regulated cycle." Therefore by restricting the post-conversion periodic harvest levels to a range around their average for only 8 decades the forest will be regulated for an indefinitely long period—in theory. The conversion period need not be as long as the post-conversion period. To illustrate, in the above example, if sufficient acreages of 10-, 20- and 30-year-old saplings and poles are already standing, the conversion period can be cut to 5 decades.

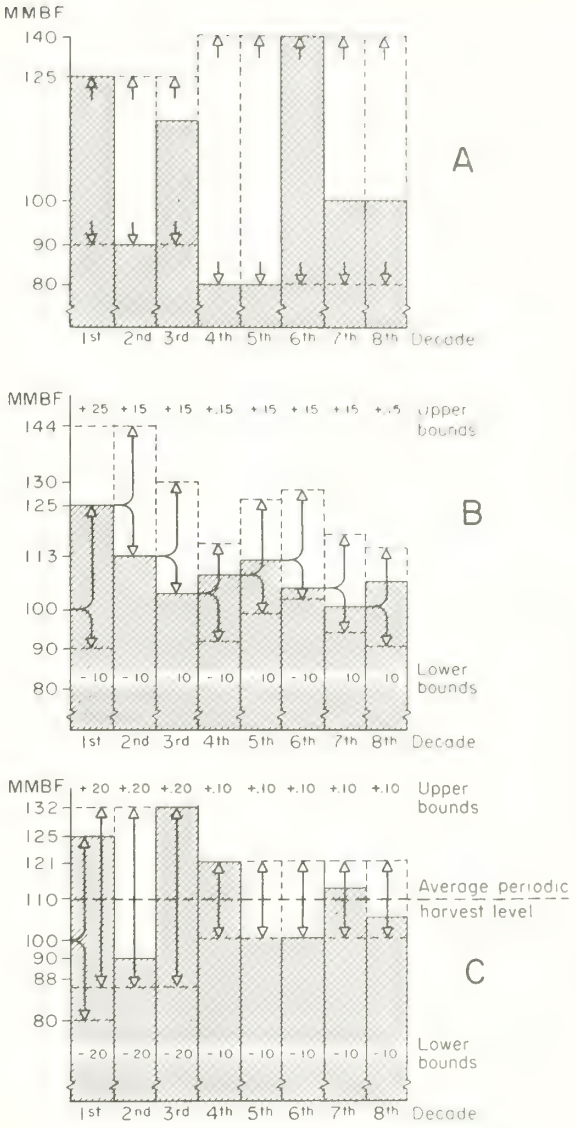



Figure 3—*Timber RAM permits three types of harvest control: A, arbitrary; B, sequential; and C, conventional. Each shaded bar represents the periodic harvest level. The tip of each arrow shows a bound. In sequential and conventional controls, the base of each arrow indicates the harvest level from which the bound was calculated. Upper and lower bounds are expressed as percentages. Except for the "current level" (100 MMBF), the harvest levels are unknown when the bounds are specified.*

But to stabilize periodic harvests, it is essential that by the end of the conversion period all overaged and poorly stocked acres be liquidated, since otherwise the second "regulated cycle" of periodic harvests will be different from the first.

If several rotation ages are contemplated, the "regulated cycle" has a much longer period. For example, for 7- and 8-decade rotations the cycle is 56 decades (the smallest common multiple of seven and eight). In these cases the post-conversion period can be limited to the longest rotation age—here 8 decades—and the forest will be for practical planning purposes adequately regulated. If total periodic stumpage is stabilized but partial cuts account for too large a percentage of the stumpage harvested in some of the post-conversion decades, the regulation constraints can be specified on the stumpage clearcut only. When the standing timber consists largely of overaged stands, a large drop in volume harvested may occur between the last decade of the conversion period and the first decade of the post-conversion period. This drop can be controlled with the "conversion link" constraint. With this constraint, the last periodic harvest level of the conversion period is restricted to a range of values around the average harvest level of the post conversion period.

When harvests are defined in terms of the number of acres harvested, and the potential productivity of the timber classes does not vary widely, stumpage harvested can be stabilized by imposing control constraints only. A conversion period extending over a number of decades equal to the longest rotation on which the regenerated timber will be managed will usually provide an adequately regulated forest. But unless the forest is already approximately regulated, wide fluctuations in periodic stumpage are likely to occur during the conversion period. Defining the harvest constraints in terms of the number of acres harvested is likely to prove useful only in peculiar situations. This option is provided in Timber RAM as a tribute to traditional forest management methods; and because its marginal cost was low.

## TIMBRAM-REPORT OPTIONS

The Timbram-Report program can translate the linear program solution into any combination of the following five documents:

- Timber Harvest Schedule *(fig. 4)*
- Problem Schedule or Objective Report *(fig. 5)*
- Harvest Report *(fig. 6)*
- Economic Report *(fig. 7)*
- Harvest Graph *(fig. 8)*

These documents are illustrated with computer printout of the Smokey Forest Case Study.

The Timber Harvest Schedule gives—for each activity selected by Timber RAM—the number of acres to be managed, the cut per acre, and the total cut for each period *(fig. 4)*. The Schedule also gives the total volume harvested in each period and a breakdown by overstory removals, clearcuts, and all other cuts.

The problem schedule is similar to the harvest schedule but gives economic data as well as harvest volume *(fig. 5)*. In addition, it shows the contribution of each activity (per acre and total) to the objective. The total objective value appears at the top of the report. Periodic totals for every input and output are given at the bottom. All revenues and costs are discounted at rates set by the user. The discount rate(s) of the objective or a zero discount rate should be included among the rates set by the user. Because this section of the program supplies large quantities of information the user should not request more periods of output than is absolutely necessary. When the Problem Schedule is not requested, an Objective Report is output automatically. This report gives only the activity name, acres managed, and the total contribution of each activity selected by Timber RAM to the objective.

The Harvest Report is an abstract of the Timber Harvest Schedule giving the total periodic and cumulative volumes harvested in each period *(fig. 6)*. Subtotals for periodic overstory removal and partial cuts are also given. The true post-conversion average harvest level is also given at the top of the report. This average will differ from the average of the post-conversion harvests calculated by Timber RAM if the Regenerated Timber is managed on two or more rotations.

The Economic Report is an abstract of the Problem Schedule giving the periodic and cumulative values for Cost, Gross Revenue 1, Gross Revenue 2, and Net Revenue *(fig. 7)*. Each can be discounted with up to five different discount rates.

The Harvest Graph displays the harvest level for every period up to the planning horizon *(fig. 8)*.

Multiple copies of the Timbram-Report output can be requested and an additional copy can be placed on magnetic tape as a permanent record if desired.

SMOKEY FOREST PROBLEM II RUN 1
NET REVENUE POTENTIAL

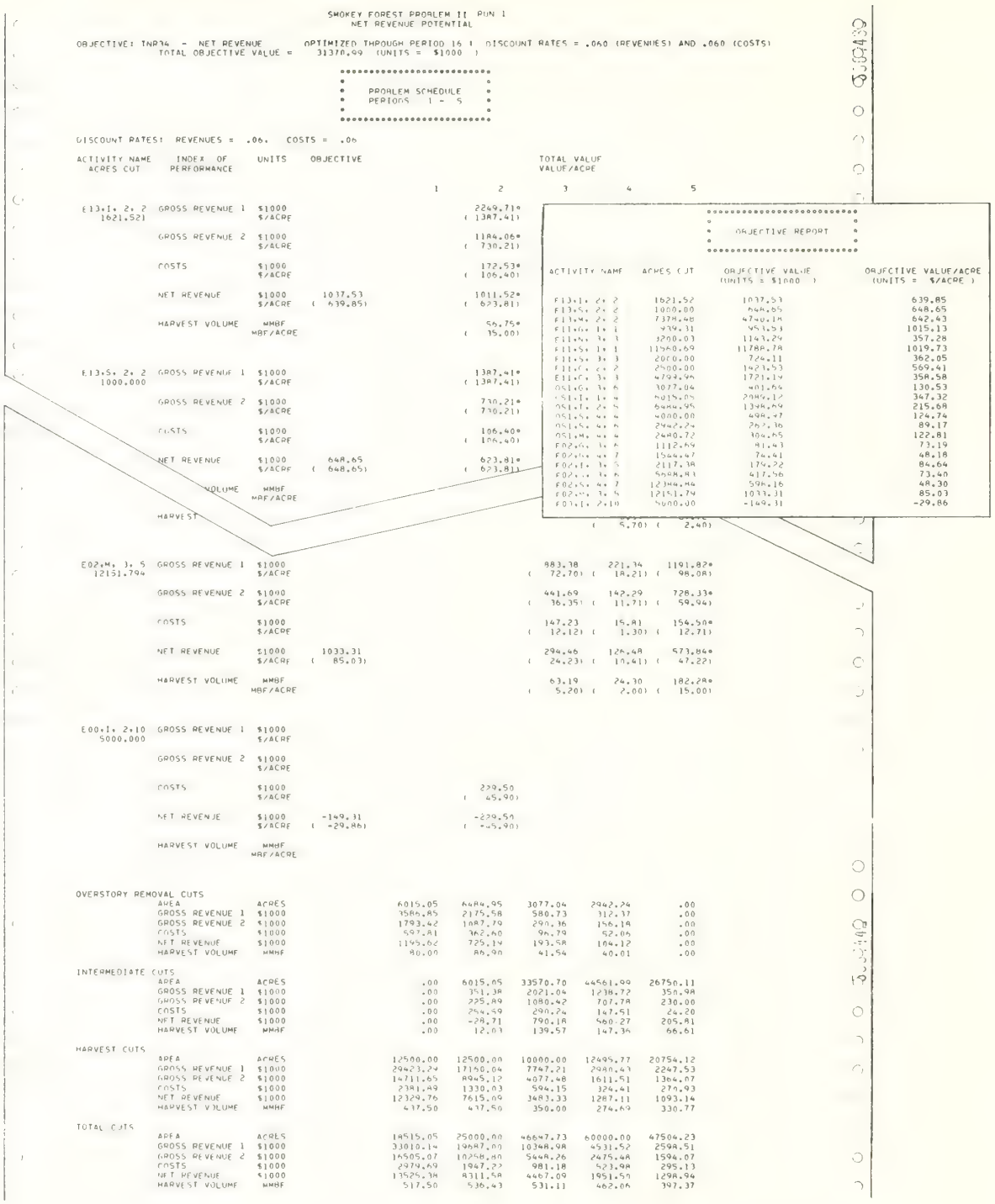
OBJECTIVE: TNR34 - NET REVENUE  OPTIMIZED THROUGH PERIOD 16 ! DISCOUNT RATES = .060 (REVENUES) AND .060 (COSTS)

TIMBER HARVEST SCHEDULE
PERIODS 1 - 10

| ACTIVITY NAME<br>ACRES CUT | TOTAL VOLUME CUT - MMBF<br>(VOLUME CUT / ACRE - MBF/AC) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| E13*I, 2, 2<br>1621.521 | | 56.75*<br>( 35.00) | | | | | 10.22<br>( 6.30) | 4.38<br>( 2.70) | 4.54<br>( 2.80) | 51.19*<br>( 31.80) |
| E13*S, 2, 2<br>1000.000 | | 35.00*<br>( 35.00) | | | | | 8.00<br>( 8.00) | 3.50<br>( 3.50) | 35.00*<br>( 35.00) | |
| E13*M, 2, 2<br>7378.483 | | 258.25*<br>( 35.00) | | | | | 46.48<br>( 6.30) | 19.92<br>( 2.70) | 221.35*<br>( 30.00) | |
| E11*G, 1, 1<br>939.310 | 32.88*<br>( 35.00) | | | | | 5.92<br>( 6.30) | 2.54<br>( 2.70) | 2.63<br>( 2.80) | 30.81*<br>( 32.80) | |
| E11*N, 3, 3<br>3200.034 | | | 112.00*<br>( 35.00) | | | | | 20.16<br>( 6.30) | 8.64<br>( 2.70) | 8.96<br>( 2.80) |
| E11*S, 1, 1<br>11560.690 | 404.62*<br>( 35.00) | | | | | 72.83<br>( 6.30) | 31.21<br>( 2.70) | 346.82*<br>( 30.00) | | |
| E11*S, 3, 3<br>2000.000 | | | 70.00*<br>( 35.00) | | | | | 16.00<br>( 8.00) | 7.00<br>( 3.50) | 70.00*<br>( 35.00) |
| E11*C, 2, 2<br>2500.000 | | 87.50*<br>( 35.00) | | | | | 15.75<br>( 6.30) | 6.75<br>( 2.70) | 75.00*<br>( 30.00) | |
| E11*C, 3, 3<br>4799.965 | | | 168.00*<br>( 35.00) | | | | | 30.24<br>( 6.30) | 12.96<br>( 2.70) | 144.00*<br>( 30.00) |
| OS1*G, 3, 6<br>3077.039 | | | 41.54*<br>( 13.50) | 8.31<br>( 2.70) | 8.62<br>( 2.80) | 62.46*<br>( 20.30) | | | | |
| OS1*I, 1, 4<br>6015.048 | 80.00*<br>( 13.30) | 12.03<br>( 2.00) | 14.44<br>( 2.40) | 93.23*<br>( 15.50) | | | | | 37.89<br>( 6.30) | 16.24<br>( 2.70) |
| OS1*I, 2, 5<br>6484.952 | | 86.90*<br>( 13.40) | 15.56<br>( 2.40) | 17.51<br>( 2.70) | 116.73*<br>( 18.00) | | | | | 40.86<br>( 6.30) |
| OS1*S, 4, 4<br>4000.000 | | | | 112.00*<br>( 28.00) | | | | | 32.00<br>( 8.00) | 14.00<br>( 3.50) |
| OS1*S, 4, 6<br>2942.240 | | | | 40.01*<br>( 13.60) | 8.24<br>( 2.80) | 59.73*<br>( 20.30) | | | | |
| OS1*M, 4, 4<br>2480.722 | | | | 69.46*<br>( 28.00) | | | | | 15.63<br>( 6.30) | 6.70<br>( 2.70) |
| E02*G, 3, 6<br>1112.694 | | | 5.79<br>( 5.20) | 2.23<br>( 2.00) | 2.67<br>( 2.40) | 18.36*<br>( 16.50) | | | | |
| E02*G, 4, 7<br>1544.466 | | | | 8.80<br>( 5.70) | 3.71<br>( 2.40) | 4.17<br>( 2.70) | 28.57*<br>( 18.50) | | | |
| E02*I, 3, 5<br>2117.378 | | | 11.01<br>( 5.20) | 4.23<br>( 2.00) | 31.76*<br>( 15.00) | | | | | 13.34<br>( 6.30) |
| E02*S, 3, 6<br>5688.831 | | | 29.58<br>( 5.20) | 11.38<br>( 2.00) | 13.65<br>( 2.40) | 93.87*<br>( 16.50) | | | | |
| E02*S, 4, 7<br>12384.836 | | | | 70.59<br>( 5.70) | 29.72<br>( 2.40) | 33.44<br>( 2.70) | 229.12*<br>( 18.50) | | | |
| E02*M, 3, 5<br>12151.794 | | | 63.19<br>( 5.20) | 24.30<br>( 2.00) | 182.28*<br>( 15.00) | | | | | 76.56<br>( 6.30) |
| E00*I, 2,10<br>5000.000 | | | | | | | 31.50<br>( 6.30) | 13.50<br>( 2.70) | 14.00<br>( 2.80) | 164.00*<br>( 32.80) |
| OVERSTORY REMOVAL CUTS | | | | | | | | | | |
| ACRES | 6015.05 | 6484.95 | 3077.04 | 2942.24 | .00 | .00 | .00 | .00 | .00 | .00 |
| MMBF | 80.00 | 86.90 | 41.54 | 40.01 | .00 | .00 | .00 | .00 | .00 | .00 |
| INTERMEDIATE CUTS | | | | | | | | | | |
| ACRES | .00 | 6015.05 | 33570.70 | 44561.99 | 26750.11 | 26429.30 | 30000.00 | 28439.31 | 29117.29 | 36449.93 |
| MMBF | .00 | 12.03 | 139.57 | 147.36 | 66.61 | 116.36 | 145.70 | 117.08 | 132.66 | 176.65 |
| HARVEST CUTS | | | | | | | | | | |
| ACRES | 12500.00 | 12500.00 | 10000.00 | 12495.77 | 20754.12 | 12820.80 | 13929.30 | 11560.69 | 11817.79 | 13421.49 |
| MMBF | 437.50 | 437.50 | 350.00 | 274.69 | 330.77 | 234.42 | 257.69 | 346.82 | 362.16 | 431.18 |
| TOTAL CUTS | | | | | | | | | | |
| ACRES | 18515.05 | 25000.00 | 46647.73 | 60000.00 | 47504.23 | 39250.11 | 43929.31 | 40000.00 | 40935.08 | 49871.41 |
| MMBF | 517.50 | 536.43 | 531.11 | 462.06 | 397.37 | 350.78 | 403.39 | 463.90 | 494.83 | 607.83 |

* = OVERSTORY REMOVAL CUT!  * = HARVEST CUT

Figure 4—*The Timber Harvest Schedule lists for each activity selected by the linear program total volume and number of acres harvested in each period. The volume per acre is given in parentheses. The volume and acres harvested in each period from all activities is totaled at the bottom, by type of cut: overstory removal, intermediate, and harvest cuts.*



SMOKEY FOREST PROBLEM II RUN 1
NET REVENUE POTENTIAL

OBJECTIVE: TNR34 - NET REVENUE OPTIMIZED THROUGH PERIOD 16 1 DISCOUNT RATES = .060 (REVENUES) AND .060 (COSTS)
TOTAL OBJECTIVE VALUE = 31370.99 (UNITS = $1000 )

PROBLEM SCHEDULE
PERIODS 1 - 5

DISCOUNT RATES: REVENUES = .06, COSTS = .06

| ACTIVITY NAME / ACRES CUT | INDEX OF PERFORMANCE | UNITS | OBJECTIVE | 1 | 2 | 3 | 4 | 5 | TOTAL VALUE VALUE/ACRE |
|---|---|---|---|---|---|---|---|---|---|
| E13.I. 2. 2 1621.521 | GROSS REVENUE 1 | $1000 | | | 2249.71* | | | | |
| | | $/ACRE | | | ( 1387.41) | | | | |
| | GROSS REVENUE 2 | $1000 | | | 1184.06* | | | | |
| | | $/ACRE | | | ( 730.21) | | | | |
| | COSTS | $1000 | | | 172.53* | | | | |
| | | $/ACRE | | | ( 106.40) | | | | |
| | NET REVENUE | $1000 | 1037.53 | | 1011.52* | | | | |
| | | $/ACRE | ( 639.85) | | ( 623.81) | | | | |
| | HARVEST VOLUME | MMBF | | | 56.75* | | | | |
| | | MBF/ACRE | | | ( 35.00) | | | | |
| E13.S. 2. 2 1000.000 | GROSS REVENUE 1 | $1000 | | | 1387.41* | | | | |
| | | $/ACRE | | | ( 1387.41) | | | | |
| | GROSS REVENUE 2 | $1000 | | | 730.21* | | | | |
| | | $/ACRE | | | ( 730.21) | | | | |
| | COSTS | $1000 | | | 106.40* | | | | |
| | | $/ACRE | | | ( 106.40) | | | | |
| | NET REVENUE | $1000 | 648.65 | | 623.81* | | | | |
| | | $/ACRE | ( 648.65) | | ( 623.81) | | | | |
| | VOLUME | MMBF | | | | | | | |
| | | MBF/ACRE | | | | | | | |
| | HARVEST | | | | | | | | |
| | | | | | ( 5.70) | ( 2.40) | | | |
| E02.M. 3. 5 12151.794 | GROSS REVENUE 1 | $1000 | | | | 883.38 | 221.34 | 1191.82* | |
| | | $/ACRE | | | | ( 72.70) | ( 18.21) | ( 98.08) | |
| | GROSS REVENUE 2 | $1000 | | | | 441.69 | 142.29 | 728.33* | |
| | | $/ACRE | | | | ( 36.35) | ( 11.71) | ( 59.94) | |
| | COSTS | $1000 | | | | 147.23 | 15.81 | 154.50* | |
| | | $/ACRE | | | | ( 12.12) | ( 1.30) | ( 12.71) | |
| | NET REVENUE | $1000 | 1033.31 | | | 294.46 | 126.48 | 573.84* | |
| | | $/ACRE | ( 85.03) | | | ( 24.23) | ( 10.41) | ( 47.22) | |
| | HARVEST VOLUME | MMBF | | | | 63.19 | 24.30 | 182.28* | |
| | | MBF/ACRE | | | | ( 5.20) | ( 2.00) | ( 15.00) | |
| E00.I. 2.10 5000.000 | GROSS REVENUE 1 | $1000 | | | | | | | |
| | | $/ACRE | | | | | | | |
| | GROSS REVENUE 2 | $1000 | | | | | | | |
| | | $/ACRE | | | | | | | |
| | COSTS | $1000 | | | 229.50 | | | | |
| | | $/ACRE | | | ( 45.90) | | | | |
| | NET REVENUE | $1000 | -149.31 | | -229.50 | | | | |
| | | $/ACRE | ( -29.86) | | ( -45.90) | | | | |
| | HARVEST VOLUME | MMBF | | | | | | | |
| | | MBF/ACRE | | | | | | | |

OBJECTIVE REPORT

| ACTIVITY NAME | ACRES CUT | OBJECTIVE VALUE (UNITS = $1000 ) | OBJECTIVE VALUE/ACRE (UNITS = $/ACRE ) |
|---|---|---|---|
| E13.I. 2. 2 | 1621.52 | 1037.53 | 639.85 |
| E13.S. 2. 2 | 1000.00 | 648.65 | 648.65 |
| E11.M. 2. 2 | 7378.48 | 4740.14 | 642.43 |
| E11.G. 1. 1 | 939.31 | 953.53 | 1015.13 |
| E11.M. 3. 3 | 3200.03 | 1143.29 | 357.28 |
| E11.S. 1. 1 | 11560.69 | 11788.78 | 1019.73 |
| E11.S. 3. 3 | 2000.00 | 724.11 | 362.05 |
| E11.G. 2. 2 | 2500.00 | 1423.53 | 569.41 |
| E11.G. 3. 3 | 4794.96 | 1721.14 | 358.58 |
| OS1.G. 3. 6 | 3077.04 | 401.64 | 130.53 |
| OS1.I. 1. 4 | 6015.05 | 2086.12 | 347.32 |
| OS1.I. 2. 5 | 6484.95 | 1398.69 | 215.68 |
| OS1.S. 4. 4 | 4000.00 | 498.47 | 124.74 |
| OS1.S. 4. 5 | 2942.24 | 263.36 | 89.17 |
| OS1.M. 4. 4 | 2440.72 | 304.85 | 122.81 |
| F02.G. 3. 6 | 1112.69 | 81.43 | 73.19 |
| F02.G. 4. 7 | 1544.47 | 74.41 | 48.18 |
| F02.I. 3. 5 | 2117.38 | 179.22 | 84.64 |
| F02.I. 3. 6 | 5698.81 | 417.56 | 73.40 |
| F02.S. 4. 7 | 12344.46 | 598.16 | 48.30 |
| F02.S. 3. 5 | 12151.74 | 1033.31 | 85.03 |
| F01.I. 2.10 | 5000.00 | -149.31 | -29.86 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| OVERSTORY REMOVAL CUTS | | | | | | | | |
| | AREA | ACRES | 6015.05 | 6484.95 | 3077.04 | 2942.24 | .00 | |
| | GROSS REVENUE 1 | $1000 | 3586.85 | 2175.58 | 580.73 | 312.37 | .00 | |
| | GROSS REVENUE 2 | $1000 | 1793.42 | 1087.79 | 290.36 | 156.19 | .00 | |
| | COSTS | $1000 | 597.81 | 362.60 | 96.79 | 52.06 | .00 | |
| | NET REVENUE | $1000 | 1195.62 | 725.19 | 193.58 | 104.12 | .00 | |
| | HARVEST VOLUME | MMBF | 80.00 | 86.90 | 41.54 | 40.01 | .00 | |
| INTERMEDIATE CUTS | | | | | | | | |
| | AREA | ACRES | .00 | 6015.05 | 33570.70 | 44561.99 | 26750.11 | |
| | GROSS REVENUE 1 | $1000 | .00 | 351.38 | 2021.04 | 1238.72 | 356.98 | |
| | GROSS REVENUE 2 | $1000 | .00 | 225.89 | 1080.42 | 707.78 | 230.00 | |
| | COSTS | $1000 | .00 | 254.59 | 290.24 | 147.51 | 24.20 | |
| | NET REVENUE | $1000 | .00 | -28.71 | 790.18 | 560.27 | 205.81 | |
| | HARVEST VOLUME | MMBF | .00 | 12.03 | 139.57 | 147.36 | 66.61 | |
| HARVEST CUTS | | | | | | | | |
| | AREA | ACRES | 12500.00 | 12500.00 | 10000.00 | 12495.77 | 20754.12 | |
| | GROSS REVENUE 1 | $1000 | 29423.24 | 17160.04 | 7747.21 | 2980.43 | 2247.53 | |
| | GROSS REVENUE 2 | $1000 | 14711.65 | 8945.12 | 4077.48 | 1611.51 | 1364.07 | |
| | COSTS | $1000 | 2381.49 | 1330.03 | 594.15 | 324.41 | 270.93 | |
| | NET REVENUE | $1000 | 12329.76 | 7615.09 | 3483.33 | 1287.11 | 1093.14 | |
| | HARVEST VOLUME | MMBF | 417.50 | 417.56 | 350.00 | 274.69 | 330.77 | |
| TOTAL CUTS | | | | | | | | |
| | AREA | ACRES | 18515.05 | 25000.00 | 46647.73 | 60000.00 | 47504.23 | |
| | GROSS REVENUE 1 | $1000 | 33010.14 | 19687.00 | 10348.98 | 4531.52 | 2598.51 | |
| | GROSS REVENUE 2 | $1000 | 16505.07 | 10258.40 | 5448.26 | 2475.48 | 1594.07 | |
| | COSTS | $1000 | 2979.29 | 1947.22 | 981.18 | 523.98 | 295.13 | |
| | NET REVENUE | $1000 | 13525.78 | 8311.58 | 4467.09 | 1951.50 | 1298.94 | |
| | HARVEST VOLUME | MMBF | 517.50 | 536.43 | 531.11 | 462.06 | 397.37 | |

Figure 5—*The Problem Schedule lists for each activity selected by the linear program the total inputs required and outputs produced in each period. Inputs and outputs per acre are given in parentheses. Periodic volume totals are given at the bottom. The total contribution of each activity to the objective is also listed. The Objective Report, an abstract of the Problem Schedule, lists for each activity the total contribution to the objective and the number of acres managed. It is automatically printed by Timbram-Report when the Problem Schedule is not requested.*

SMOKEY FOREST PROBLEM II RUN 1
NET REVENUE POTENTIAL

OBJECTIVE: TNR34 = NET REVENUE  OPTIMIZED THROUGH PERIOD 16 ; DISCOUNT RATES = .060 (REVENUES) AND .060 (COSTS)
TOTAL OBJECTIVE VALUE = 31370.99 (UNITS = $1000 )

LONG RANGE SUSTAINED YIELD AVERAGE = 673.45 MMBF/DECADE

HARVEST REPORT

| | OVERSTORY REMOVAL CUTS | | | INTERMEDIATE CUTS | | | HARVEST CUTS | | | TOTAL CUTS | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PERIOD | ACRES | MMBF PERIODIC | MMBF TOTAL | ACRES | MMBF PERIODIC | MMBF TOTAL | ACRES | MMBF PERIODIC | MMBF TOTAL | ACRES | MMBF PERIODIC | MMBF TOTAL |
| 1 | 6015. | 80.00 | 80.00 | 0. | .00 | .00 | 12500. | 437.50 | 437.50 | 18515. | 517.50 | 517.50 |
| 2 | 6485. | 86.90 | 166.90 | 6015. | 12.03 | 12.03 | 12500. | 437.50 | 875.00 | 25000. | 536.43 | 1053.93 |
| 3 | 3077. | 41.54 | 208.44 | 33571. | 139.57 | 151.60 | 10000. | 350.00 | 1225.00 | 46648. | 531.11 | 1585.04 |
| 4 | 2942. | 40.01 | 248.45 | 44562. | 147.36 | 298.95 | 12496. | 274.69 | 1499.69 | 60000. | 462.06 | 2047.10 |
| 5 | 0. | .00 | 248.45 | 26750. | 66.61 | 365.56 | 20754. | 330.77 | 1830.46 | 47504. | 397.37 | 2444.47 |
| 6 | 0. | .00 | 248.45 | 26429. | 116.36 | 481.92 | 12821. | 234.42 | 2064.88 | 39250. | 350.78 | 2795.25 |
| 7 | 0. | .00 | 248.45 | 30000. | 145.70 | 627.62 | 13929. | 257.69 | 2322.57 | 43929. | 403.39 | 3198.64 |
| 8 | 0. | .00 | 248.45 | 28439. | 117.08 | 744.70 | 11561. | 346.82 | 2669.39 | 40000. | 463.90 | 3662.54 |
| 9 | 0. | .00 | 248.45 | 29117. | 132.66 | 877.36 | 11818. | 362.16 | 3031.55 | 40935. | 494.83 | 4157.37 |
| 10 | 0. | .00 | 248.45 | 36450. | 176.65 | 1054.01 | 13421. | 431.18 | 3462.74 | 49871. | 607.83 | 4765.21 |
| 11 | 0. | .00 | 248.45 | 39590. | 175.44 | 1229.46 | 9681. | 319.38 | 3782.12 | 49271. | 494.83 | 5260.03 |
| 12 | 0. | .00 | 248.45 | 35352. | 180.39 | 1409.85 | 18167. | 561.85 | 4343.97 | 53519. | 742.24 | 6002.27 |
| 13 | 0. | .00 | 248.45 | 29680. | 158.00 | 1567.85 | 17233. | 584.24 | 4928.21 | 46913. | 742.24 | 6744.51 |
| 14 | 0. | .00 | 248.45 | 24923. | 141.18 | 1709.03 | 16575. | 601.06 | 5529.27 | 41498. | 742.24 | 7486.76 |
| 15 | 0. | .00 | 248.45 | 25239. | 148.73 | 1857.77 | 13105. | 466.40 | 5995.67 | 38344. | 615.14 | 8101.89 |
| 16 | 0. | .00 | 248.45 | 24042. | 128.18 | 1985.94 | 10878. | 380.75 | 6376.42 | 34920. | 508.93 | 8610.82 |
| 17 | 0. | .00 | 248.45 | 34469. | 205.70 | 2191.65 | 7739. | 275.57 | 6651.99 | 42208. | 481.27 | 9092.09 |
| 18 | 0. | .00 | 248.45 | 38600. | 214.25 | 2405.90 | 13102. | 491.69 | 7143.68 | 51703. | 705.94 | 9798.03 |
| 19 | 0. | .00 | 248.45 | 39823. | 216.97 | 2622.87 | 15352. | 553.31 | 7696.99 | 55175. | 770.29 | 10568.32 |
| 20 | 0. | .00 | 248.45 | 38282. | 197.26 | 2820.13 | 14646. | 542.69 | 8239.68 | 52928. | 739.95 | 11308.27 |

Figure 6—*The Harvest Report lists by type of cuts the total volume and acres harvested in each period.*

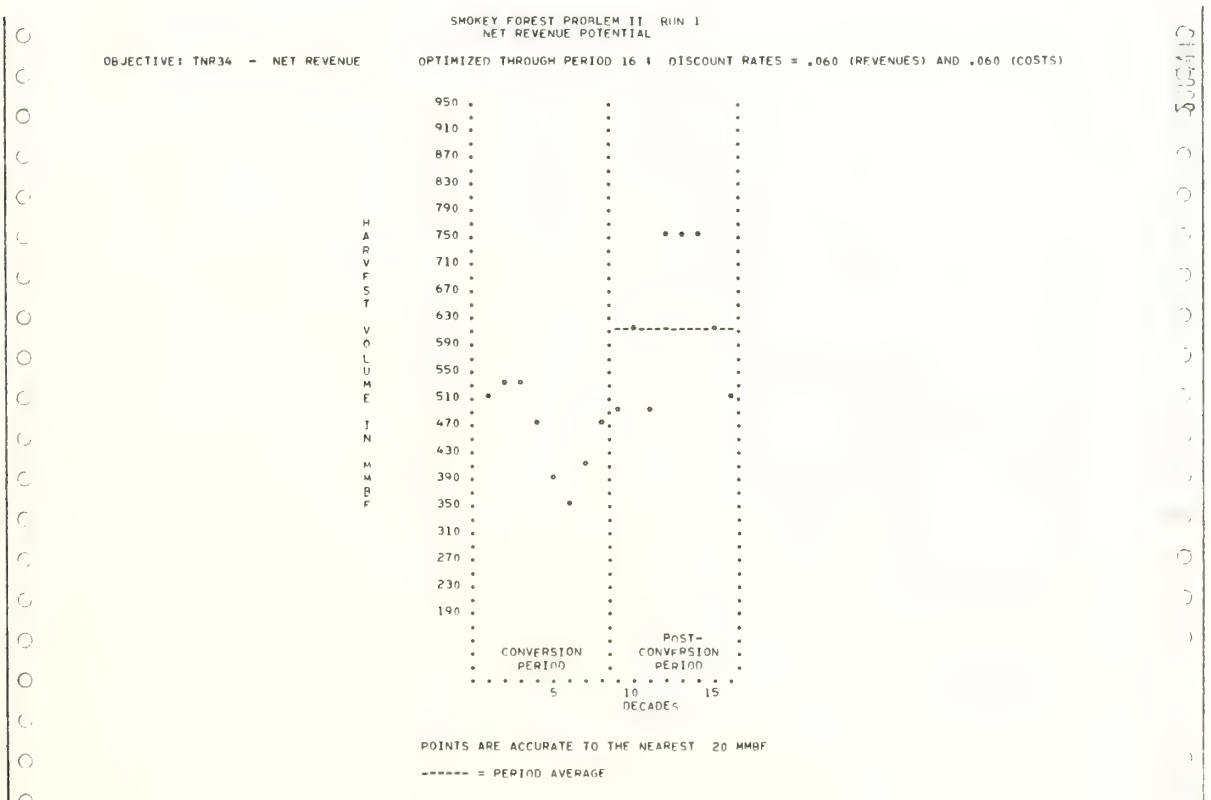



Figure 8—*The Harvest Graph displays the total volume harvested in each period up to the "planning horizon."*

*(See page 16 for Figure 7)*

SMOKEY FOREST PROBLEM II RUN 1
NET REVENUE POTENTIAL

OBJECTIVE: TNR34 = NET REVENUE OPTIMIZED THROUGH PERIOD 16 ; DISCOUNT RATES = .060 (REVENUES) AND .060 (COSTS)
TOTAL OBJECTIVE VALUE = 31370.99 (UNITS = $1000 )

ECONOMIC REPORT

(UNITS = $1000)

| | DISCOUNT RATES | | GROSS REVENUE 1 | | GROSS REVENUE 2 | | COSTS | | NET REVENUE | |
|---|---|---|---|---|---|---|---|---|---|---|
| PERIOD | REVENUES | COSTS | PERIODIC | TOTAL | PERIODIC | TOTAL | PERIODIC | TOTAL | PERIODIC | TOTAL |
| 1 | .000 | .000 | 44175.01 | 44175.01 | 22087.50 | 22087.50 | 3987.50 | 3987.50 | 18100.00 | 18100.00 |
| | .100 | .100 | 27429.21 | 27429.21 | 13714.60 | 13714.60 | 2475.92 | 2475.92 | 11238.68 | 11238.68 |
| | .060 | .060 | 33010.14 | 33010.14 | 16505.07 | 16505.07 | 2979.69 | 2979.69 | 13525.38 | 13525.38 |
| 2 | .000 | .000 | 47181.02 | 91356.03 | 24585.81 | 46673.32 | 4666.64 | 8654.14 | 19919.18 | 38019.18 |
| | .100 | .100 | 11294.76 | 38723.97 | 5885.65 | 19600.25 | 1117.16 | 3593.08 | 4768.49 | 16007.17 |
| | .060 | .060 | 19687.00 | 52697.13 | 10258.80 | 26763.87 | 1947.22 | 4926.92 | 8311.58 | 21836.95 |
| 3 | .000 | .000 | 44416.45 | 135772.48 | 23383.23 | 70056.54 | 4211.08 | 12865.21 | 19172.15 | 57191.33 |
| | .100 | .100 | 4099.46 | 42823.43 | 2158.18 | 21758.43 | 388.67 | 3981.75 | 1769.51 | 17776.68 |
| | .060 | .060 | 10348.98 | 63046.11 | 5448.26 | 32212.13 | 981.18 | 5908.09 | 4467.09 | 26304.04 |
| 4 | .000 | .000 | 34829.61 | 170602.09 | 19026.73 | 89083.27 | 4027.34 | 16892.55 | 14999.39 | 72190.72 |
| | .100 | .100 | 1239.38 | 44062.81 | 677.05 | 22435.48 | 143.31 | 4125.05 | 533.74 | 18310.42 |
| | .060 | .060 | 4531.52 | 67577.63 | 2475.48 | 34687.61 | 523.98 | 6432.07 | 1951.50 | 28255.54 |
| 5 | .000 | .000 | 35767.39 | 206369.49 | 21941.71 | 111024.98 | 4062.29 | 20954.84 | 17879.43 | 90070.14 |
| | .100 | .100 | 490.70 | 44553.51 | 301.02 | 22736.50 | 55.73 | 4180.79 | 245.29 | 18555.72 |
| | .060 | .060 | 2598.51 | 70176.13 | 1594.07 | 36281.68 | 295.13 | 6727.20 | 1298.94 | 29554.48 |
| 6 | .000 | .000 | 30466.54 | 236834.02 | 18346.28 | 129371.26 | 3429.71 | 24384.55 | 14916.57 | 104986.71 |
| | .100 | .100 | 161.14 | 44714.65 | 97.04 | 22833.54 | 18.14 | 4198.93 | 78.90 | 18634.61 |
| | .060 | .060 | 1235.87 | 71412.00 | 744.26 | 37025.94 | 139.13 | 6866.33 | 605.13 | 30159.61 |
| 7 | .000 | .000 | 36361.71 | 273195.73 | 21835.78 | 151207.03 | 3969.64 | 28354.19 | 17866.14 | 122852.84 |
| | .100 | .100 | 74.15 | 44788.80 | 44.53 | 22878.07 | 8.10 | 4207.02 | 36.43 | 18671.05 |
| | .060 | .060 | 823.69 | 72235.69 | 494.64 | 37520.58 | 89.92 | 6956.25 | 404.72 | 30564.33 |
| 8 | .000 | .000 | 40082.57 | 313278.30 | 28110.55 | 179317.58 | 3460.75 | 31814.94 | 24649.80 | 147502.64 |
| | .100 | .100 | 31.51 | 44820.31 | 22.10 | 22900.17 | 2.72 | 4209.74 | 19.38 | 18690.43 |
| | .060 | .060 | 507.01 | 72742.70 | 355.57 | 37876.15 | 43.78 | 7000.03 | 311.80 | 30876.12 |
| 9 | .000 | .000 | 43441.10 | 356719.39 | 30417.79 | 209735.37 | 3719.00 | 35533.94 | 26698.80 | 174201.44 |
| | .100 | .100 | 13.17 | 44833.48 | 9.22 | 22909.39 | 1.13 | 4210.87 | 8.09 | 18698.52 |
| | .060 | .060 | 306.83 | 73049.53 | 214.85 | 38091.00 | 26.27 | 7026.30 | 188.58 | 31064.70 |
| 10 | .000 | .000 | 54634.56 | 411353.95 | 38462.94 | 248198.31 | 4612.43 | 40146.37 | 33850.51 | 208051.95 |
| | .100 | .100 | 6.39 | 44839.87 | 4.50 | 22913.89 | .54 | 4211.41 | 3.96 | 18702.48 |
| | .060 | .060 | 215.48 | 73265.01 | 151.70 | 38242.70 | 18.19 | 7044.49 | 133.51 | 31198.21 |
| 11 | .000 | .000 | 44950.36 | 456304.30 | 31301.71 | 279500.02 | 3624.62 | 43770.99 | 27677.08 | 235729.03 |
| | .100 | .100 | 2.03 | 44841.89 | 1.41 | 22915.30 | .16 | 4211.57 | 1.25 | 18703.72 |
| | .060 | .060 | 99.00 | 73364.01 | 68.94 | 38311.64 | 7.98 | 7052.47 | 60.95 | 31259.17 |
| 12 | .000 | .000 | 67236.25 | 523540.55 | 47765.56 | 327265.57 | 5540.06 | 49311.05 | 42225.50 | 277954.53 |
| | .100 | .100 | 1.17 | 44843.06 | .83 | 22916.13 | .10 | 4211.67 | .73 | 18704.46 |
| | .060 | .060 | 82.69 | 73446.69 | 58.74 | 38370.38 | 6.81 | 7059.28 | 51.93 | 31311.09 |
| 13 | .000 | .000 | 71193.05 | 594733.59 | 50567.98 | 377833.55 | 5293.66 | 54604.71 | 45274.32 | 323228.85 |
| | .100 | .100 | .48 | 44843.53 | .34 | 22916.47 | .04 | 4211.70 | .30 | 18704.76 |
| | .060 | .060 | 48.89 | 73495.58 | 34.73 | 38405.10 | 3.64 | 7062.92 | 31.09 | 31342.18 |
| 14 | .000 | .000 | 72800.34 | 667533.93 | 50864.59 | 428698.14 | 5178.39 | 59783.10 | 45686.20 | 368915.05 |
| | .100 | .100 | .19 | 44843.72 | .13 | 22916.60 | .01 | 4211.72 | .12 | 18704.88 |
| | .060 | .060 | 27.92 | 73523.50 | 19.50 | 38424.61 | 1.99 | 7064.91 | 17.52 | 31359.70 |
| 15 | .000 | .000 | 58760.96 | 726294.88 | 40579.45 | 469277.59 | 4398.85 | 64181.95 | 36180.60 | 405095.64 |
| | .100 | .100 | .06 | 44843.78 | .04 | 22916.64 | .00 | 4211.72 | .04 | 18704.92 |
| | .060 | .060 | 12.58 | 73536.08 | 8.69 | 38433.29 | .94 | 7065.85 | 7.75 | 31367.45 |
| 16 | .000 | .000 | 48163.07 | 774457.95 | 33218.87 | 502496.46 | 3584.57 | 67766.52 | 29634.31 | 434729.95 |
| | .100 | .100 | .02 | 44843.80 | .01 | 22916.65 | .00 | 4211.72 | .01 | 18704.93 |
| | .060 | .060 | 5.76 | 73541.84 | 3.97 | 38437.27 | .43 | 7066.28 | 3.54 | 31370.99 |
| 17 | .000 | .000 | 44489.41 | 818947.36 | 30092.75 | 532589.21 | 3597.40 | 71363.92 | 26495.35 | 461225.30 |
| | .100 | .100 | .01 | 44843.80 | .00 | 22916.65 | .00 | 4211.72 | .00 | 18704.93 |
| | .060 | .060 | 2.97 | 73544.81 | 2.01 | 38439.27 | .24 | 7066.52 | 1.77 | 31372.76 |
| 18 | .000 | .000 | 69068.77 | 888016.12 | 47981.71 | 580570.91 | 5005.16 | 76369.08 | 42976.55 | 504201.84 |
| | .100 | .100 | .00 | 44843.81 | .00 | 22916.66 | .00 | 4211.72 | .00 | 18704.93 |
| | .060 | .060 | 2.57 | 73547.38 | 1.79 | 38441.06 | .19 | 7066.70 | 1.60 | 31374.36 |
| 19 | .000 | .000 | 74085.90 | 962102.02 | 51282.08 | 631852.98 | 5435.53 | 81804.61 | 45846.54 | 550048.38 |
| | .100 | .100 | .00 | 44843.81 | .00 | 22916.66 | .00 | 4211.72 | .00 | 18704.93 |
| | .060 | .060 | 1.54 | 73548.92 | 1.07 | 38442.13 | .11 | 7066.82 | .95 | 31375.32 |
| 20 | .000 | .000 | 72957.14 | 1035059.15 | 51001.44 | 682854.42 | 5102.73 | 86907.34 | 45898.72 | 595947.09 |
| | .100 | .100 | .00 | 44843.81 | .00 | 22916.66 | .00 | 4211.72 | .00 | 18704.93 |
| | .060 | .060 | .85 | 73549.77 | .59 | 38442.72 | .06 | 7066.87 | .53 | 31375.85 |

Figure 7—*The Economic Report lists by period the total discounted revenues and costs. Revenues and costs can be discounted at different rates. Up to five different pairs of discount rates can be specified.*

# CONCLUSIONS

The solution to a Timber RAM problem is not necessarily the best combination of activities. It is only a combination which is consistent with specified constraints and which maximizes—or minimizes—a particular index of performance. Managers and planners must then evaluate alternative combinations of activities by determining the extent to which each combination meets social, economic, and ecological needs and political realities. This evaluation is too complex and too subtle to be programed for computers; in our society, it lies largely outside the domain of economic analysis.

Timber RAM simplifies the planning task by shifting to computers the burden of calculating alternative plans with which planners and managers can determine whether policies governing the multiple-use management of forest land are mutually consistent. And when policies are consistent, Timber RAM makes it possible to estimate the inputs required and the outputs produced should these policies be carried out efficiently. The complexity of natural, social, and economic phenomena dictates that these estimates will be at best crude. Hence, Timber RAM estimates must be considered only first approximations to the actual inputs and outputs. Nevertheless a tool such as Timber RAM places a high premium on the improvement of data gathering and processing, for this in turn will lead to improvement of the estimates.

Timber RAM not only permits evaluation of current policies, it also can be used to develop new policies. It will indicate whether with current and expected technology a policy can be carried out and at what cost; whether it can be carried out only by modifying related policies; and how much these policies must be changed.

The inputs and outputs estimated by Timber RAM are limited to timber, land area, and related costs and revenues. The interaction of range, watershed, recreation, wildlife, and timber management policies can be partially evaluated in terms of the Timber RAM inputs and outputs. The impact of extending recreation use, or stream and wildlife protection, can be introduced in the Timber RAM analysis by defining appropriate activities and manipulating timber class acreages. Extension—or contraction—of range areas can be handled in a similar manner. And the analysis of these policies can be integrated with policies defining the desired timber production profile.

Timber RAM is thus the first step toward a quantitative evaluation of multiple-use interactions. Work on the Resources Allocation Method seeks to extend the list of estimates to include as many inputs and outputs of multiple-use forest management as the current state of the arts reasonably permits. In the measure in which this attempt succeeds, RAM schedules and reports will permit a still more rational evaluation of the interaction of multiple-use management policies.

# APPENDIX

## *Generating Activities with the Management Alternative Options of Timbram-Matrix*

Even if all the stands of a forest are combined into 20 or fewer timber classes, several hundred activities are likely to be generated for each Timber RAM problem. The data preparation and processing are greatly reduced and simplified if these activities are defined with the management alternative options of the Timbram-Matrix program. A management alternative is defined by specifying a sequence of treatments for a particular timber class, and also specifying one or more schedulings for these treatments.

### Specifying Sequences of Treatments

To simplify the exposition, let us call any timber already established at the beginning of the first planning period "Standing Timber," and use the term "Regenerated Timber" for stands regenerated from the first planning period onward. Regenerated Timber includes the timber planted on land which was unstocked at the beginning of the first period as well as the timber planted to replace Standing Timber.

In general, the Standing Timber and Regenerated Timber of a given timber class will be managed with very different silvicultural treatments. The Standing Timber may be poorly stocked, or overage, in which case it will normally be liquidated, by clearcutting. The Regenerated Timber of this same timber class will presumably be well stocked, and it may be managed intensively by partial cutting. In addition, the Standing Timber may be clearcut over many decades—hence at a wide range of ages—to redistribute the acreage among age classes. The Regenerated Timber, on the other hand, will generally be harvested at one given rotation age—or at most at two or three different rotation ages. These differences in silvicultural treatments for Standing and Regenerated Timber can be specified with the Timbram-Matrix management alternative options.

For a given management alternative, the Regenerated Timber treatments are specified by a rotation age and by the estimated stumpage volume per acre which the treatments will yield for every decade of the rotation. This sequence of cuts and yields is assumed to repeat itself cyclically. For example, clearcutting Regenerated Timber on an 8-decade rotation would be specified as zero volume for the first 7 decades and a clearcut volume for the eighth decade. Any sequence of partial cuts can be easily specified simply by estimating the partial cuts and final cut yields, and assigning them to the appropriate decade. For example, partial cuts in the 3 decades preceding the harvest cut would be specified by assigning the estimated yield from these cuts to the fifth, sixth and seventh decade.

The Standing Timber treatments are specified by a "type of management" (clearcut only, clearcut preceded by partial cuts on a 10- or 20-year cycle, etc.,. . .) and yields for entry, re-entry and harvest cuts for every age at which these cuts might occur. The Standing Timber yields and the Regenerated yields are consolidated into a Volume Data Class and entered on the Timbram-Matrix data input forms. Similar forms must be prepared for the corresponding costs and revenues data.

With the Timbram-Matrix options, management alternatives can be defined for treatments involving:

- variations in the rotation age of the Regenerated Timber
- the introduction of genetically improved stock
- different logging practices or utilization standards
- the introduction of partial cuts in the Standing Timber on a 10- or 20-year cycle
- various techniques of reforestation
- the removal of the overstory in two-story timber classes—after which the understory can be managed as any other type of Standing Timber
- variations in the level of partial cuts and harvest cuts representing alternative cutting regimes, precommercial thinning, fertilizing, etc.

### Specifying Schedulings of Treatment Sequences

In general, a given sequence of treatments can be executed on several time tables; clearcutting mature old growth, for example, can be stretched over several decades to redistribute the acreage among age classes. To schedule a sequence of treatments requiring no partial cutting in the Standing Timber, the first and last periods in which the clearcutting can occur must be specified. When partial cuts are also planned in the Standing Timber, the first and last periods in which the stands can be entered for partial cutting must also be specified.

Consider for example a forest that has 20,000

acres in stands with these characteristics:

- a well-stocked understory which will average 40 years of age in the first planning decade
- a mature overstory.

To reduce data processing costs, let us combine these stands into a single timber class–called OS1.[4] After the removal of the overstory, let us schedule partial cuts on a 10-year cycle until the Standing Timber is harvest cut and let us manage the Regenerated Timber "intensively" on an 80-year rotation up to the planning horizon in the 16th decade *(fig. 9)*. This sequence of treatments partially defines a management alternative which we name OS1 X.[5] To complete the definition of this management alternative we must specify the decade of first and last entry as well as the decade of first and last harvest since the type of harvesting calls for partial cuts in the standing timber. The overstory being mature, let us specify the first entry–which will be an overstory removal–for the first decade. Let us delay the first harvest cut until the understory which is 40 years old in the first

[4]Timber classes are identified in Timber RAM by any three "alphanumeric" characters. The alphanumeric characters consist of the set of 26 letters and 10 digits.

[5]The name of a management alternative OS1 X consists of three characters identifying the timber class (OS1) followed by a single alphanumeric character identifying the sequence of silvicultural treatments (X).

Sequence of treatments
Standing Timber: overstory removal, partial cuts on a 10-year cycle until the final harvest cut, then plant.
Regenerated Timber: partial cut at age 50, 60, and 70; final harvest cut at age 80, then plant.

Scheduling of treatments
First Entry: Period 1 First Harvest: Period 4
Last Entry: Period 5 Last Harvest: Period 6

| PERIOD (decade) | ACTIVITIES OS1 X | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 14 | 24 | 34 | 44 | 15 | 25 | 35 | 45 | 55 | 16 | 26 | 36 | 46 | 56 | |
| 1 | 13.3 (E) | | | | 13.3 (E) | | | | | 13.3 (E) | | | | | |
| 2 | 2.0 (RE) | 13.4 (E) | | | 2.0 (RE) | 13.4 (E) | | | | 2.0 (RE) | 13.4 (E) | | | | STANDING |
| 3 | 2.4 (RE) | 2.4 (RE) | 13.5 (E) | | 2.4 (RE) | 2.4 (RE) | 13.5 (E) | | | 2.4 (RE) | 2.4 (RE) | 13.5 (E) | | | TIMBER |
| 4 | 15.5 (IHC) | 15.5 (IHC) | 15.5 (IHC) | 28.0 (HC) | 2.7 (RE) | 2.7 (RE) | 2.7 (RE) | 13.6 (E) | | 2.7 (RE) | 2.7 (RE) | 2.7 (RE) | 13.6 (E) | | YIELDS |
| 5 | | | | | 18.0 (IHC) | 18.0 (IHC) | 18.0 (IHC) | 18.0 (IHC) | 29.0 (HC) | 2.8 (RE) | 2.8 (RE) | 2.8 (RE) | 2.8 (RE) | 13.5 (E) | |
| 6 | | | | | | | | | | 20.3 (IHC) | 20.3 (IHC) | 20.3 (IHC) | 20.3 (IHC) | 20.3 (IHC) | |
| 7 | | | | | | | | | | | | | | | |
| 8 | | | | | | | | | | | | | | | |
| 9 | 6.3 (E) | 6.3 (E) | 6.3 (E) | 6.3 (E) | | | | | | | | | | | |
| 10 | 2.7 (RE) | 2.7 (RE) | 2.7 (RE) | 2.7 (RE) | 6.3 (E) | 6.3 (E) | 6.3 (E) | 6.3 (E) | 6.3 (E) | | | | | | REGENERATED |
| 11 | 2.8 (RE) | 2.8 (RE) | 2.8 (RE) | 2.8 (RE) | 2.7 (RE) | 2.7 (RE) | 2.7 (RE) | 2.7 (RE) | 2.7 (RE) | 6.3 (E) | 6.3 (E) | 6.3 (E) | 6.3 (E) | 6.3 (E) | TIMBER |
| 12 | 32.8 (IHC) | 32.8 (IHC) | 32.8 (IHC) | 32.8 (IHC) | 2.8 (RE) | 2.8 (RE) | 2.8 (RE) | 2.8 (RE) | 2.8 (RE) | 2.7 (RE) | 2.7 (RE) | 2.7 (RE) | 2.7 (RE) | 2.7 (RE) | YIELDS |
| 13 | | | | | 32.8 (IHC) | 32.8 (IHC) | 32.8 (IHC) | 32.8 (IHC) | 32.8 (IHC) | 2.8 (RE) | 2.8 (RE) | 2.8 (RE) | 2.8 (RE) | 2.8 (RE) | |
| 14 | | | | | | | | | | 32.8 (IHC) | 32.8 (IHC) | 32.8 (IHC) | 32.8 (IHC) | 32.8 (IHC) | |
| 15 | | | | | | | | | | | | | | | |
| 16 | | | | | | | | | | | | | | | |

Volumes are in MBF/ACRE

E: entry cut
RE: re-entry cut

IHC: intensive harvest cut (last of a series of cuts)
HC: harvest cut (clear cut)

Figure 9–*Management alternative OS1 and corresponding activities generated with Timbram-Matrix.*

decade reaches 70 years, by specifying the first harvest in the fourth decade. The last entry and the last harvest can be set at any decade which is consistent with the first entry and harvest selected. For example, the last entry cannot be specified before the first entry, or after the last harvest. Let us set the last entry in the fifth decade and the last harvest in the sixth decade. For management alternative OS1 X, Timbram-Matrix will generate 14 activities, some with many intermediate cuts before the harvest cut *(fig. 9)*. For example, activity OS1 X 26:[6] remove the overstory in the second decade, partial cut in the third, fourth and fifth decades, and harvest cut in the sixth decade when the timber class averages 90 years.

The total number of Standing Timber cuts in every activity generated for a particular management alternative can be specified with the maximum number of cuts option. For management alternative OS1 X setting the maximum number of cuts at 3 would eliminate activities 14, 15, 25, 16, 26, and 36 since these six activities all have more than three cuts in the Standing Timber *(fig. 10)*. If spectacular growth were expected after the removal of the overstory, activities which schedule clearcutting of both the overstory and the understory in the same period should be eliminated. This could easily be done by setting "minimum number of cuts" at 2. Then Timbram-Matrix would not generate activities 44 and 55 *(fig. 10)*.

The management alternative options of Timbram-Matrix, make practical the consideration of many different sequences and schedulings of silvicultural treatments for each timber class.

[6]The name of an activity consists of the management alternative name followed by two characters indicating the period of entry and the period of harvest of the Standing Timber; period 10 is indicated by "A," period 11 by "B."

| PERIOD (decade) | ACTIVITIES OS1 X | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 14 | 24 | 34 | 44 | 15 | 25 | 35 | 45 | 55 | 16 | 26 | 36 | 46 | 56 |
| 1 | 13.3 (E) | | | | 13.3 (E) | | | | | 13.3 (E) | | | | |
| 2 | 2.0 (RE) | 13.4 (E) | | | 2.0 (RE) | 13.4 (E) | | | | 2.0 (RE) | 13.4 (E) | | | |
| 3 | 2.4 (RE) | 2.4 (RE) | 13.5 (E) | | 2.4 (RE) | 2.4 (RE) | 13.5 (E) | | | 2.4 (RE) | 2.4 (RE) | 13.5 (E) | | |
| 4 | 15.5 (IHC) | 15.5 (IHC) | 15.5 (IHC) | 28.0 (HC) | 2.7 (RE) | 2.7 (RE) | 2.7 (RE) | 13.6 (E) | | 2.7 (RE) | 2.7 (RE) | 2.7 (RE) | 13.6 (E) | |
| 5 | | | | | 18.0 (IHC) | 18.0 (IHC) | 18.0 (IHC) | 18.0 (IHC) | 29.0 (HC) | 2.8 (RE) | 2.8 (RE) | 2.8 (RE) | 2.8 (RE) | 13.5 (E) |
| 6 | | | | | | | | | | 20.3 (IHC) | 20.3 (IHC) | 20.3 (IHC) | 20.3 (IHC) | 20.3 (IHC) |
| 7 | | | | | | | | | | | | | | |
| 8 | | | | | | | | | | | | | | |

Activities eliminated if maximum number of cuts were set = 3

Activities eliminated if minimum number of cuts were set = 2

Figure 10—*Activities deleted with the "maximum" and "minimum number of cuts" option. Only the volume outputs for the Standing Timber are shown here.*

# SUMMARY

Navon, Daniel I.

1971. **Timber RAM. . .a long-range planning method for commercial timber lands under multiple-use management.** Berkeley, Calif., Pacific SW. Forest & Range Exp. Sta., 22 p., illus. (USDA Forest Serv. Res. Paper PSW-70)

*Oxford:* 624:U681.3.

*Retrieval Terms:* Timber RAM; timber management planning; multiple-use management; linear programing; simulation; computer programs.

Timber RAM (Resource Allocation Method) is a computerized method for generating long-range plans for forest lands under multiple-use management. To generate such plans, three computer programs must be used: (a) Timbram-Matrix, (b) a linear programing (LP) code, and (c) Timbram-Report. LP codes for every medium and large computer are available and can be obtained commercially. The Timbram-Matrix and Timbram-Report programs and a four-part User's Manual are available on request to the Director, Pacific Southwest Forest and Range Experiment Station, P. O. Box 245, Berkeley, California 94701. Timbram-Matrix and Report can be used only on the UNIVAC 1108 (Exec II) computer with the ILONA LP code. These two programs were designed to facilitate their adaptation to other computers and LP codes.

Part I of the User's Manual– *The Smokey Forest Case Study*–illustrates how Timber RAM could be used to plan the management of a hypothetical publicly owned forest. Part II is *The Foresters' Guide* with which a professionally trained forester familiar with electronic data processing procedures can generate Timber RAM plans. Part III–the *Mathematical Programers Guide*–describes the mathematical relations used in Timber RAM. Part IV– *The Computer Programers Guide*–includes all subroutines used in Timbram-Matrix and Timbram-Report, and instructions for adapting these programs to various computers and LP codes.

Each Timber RAM plan consists of cutting and reforestation schedules and related reports for a sequence of decades extending up to 350 years from the present. The schedules establish for each decade how many acres of each timber class will be harvested, the type of cut–and implicitly the type of reforestation–how much stumpage will be removed, and what the corresponding discounted costs and revenues will be. In the Reports, the stumpage harvested in every timber class and the corresponding discounted costs and revenues are totalled by period.

For each timber class, alternative sequences of silvicultural treatments referred to as "activities" are defined. These activities may differ with respect to the type and timing of the treatments. Linear programing is used to find a combination of these activities which maximizes stumpage or discounted revenues, or minimizes discounted costs; stumpage, revenues and costs can be summed for any sequence of decades beginning with the first decade. In addition, the combination of activities can be required to satisfy "constraints" on the periodic level of stumpage harvested, revenues and costs. "Harvest control and regulation constraints" can also be specified to control the flow of stumpage and to regulate the forest. The combination of activities is then translated into a Timber RAM plan. Alternative combinations of activities can be obtained by changing the objective, the constraints, or the activities.

The corresponding alternative Timber RAM plans can be used to establish whether current management policies are consistent with each other, with the available natural resources, and with expected financial resources. Changes in multiple-use management policies on scenic areas, erodible soils, roading, snow management, and cutting practices can be evaluated in terms of their impact on stumpage harvested, costs and revenues.

Once a plan has been selected, the schedules and reports provide management guidelines and targets for annual plans. To facilitate this shortrun planning task, schedules and reports can be prepared for the first and second half of the first decade.

The use of linear programing greatly simplifies the problem of finding a combination of activities, but it requires making a "linearity" assumption: that for any timber class, the stumpage, revenues and costs are proportional to the number of acres treated. Because average costs and revenues are not constant with respect to the number of acres treated, Timber RAM plans may be biased. This bias can be estimated and

must be corrected before operational decisions are made. If the bias cannot be reduced to an acceptable level, more sophisticated programing methods than linear programing must be used to develop long-range plans.

Timber RAM can be used to generate plans which are efficient with respect to stumpage harvested, costs or revenues, and which are consistent with specific management policies and available resources. Because social values and political realities cannot be reduced to mathematical relations, the final selection of a Timber RAM plan must remain intuitive.

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PACIFIC SOUTHWEST
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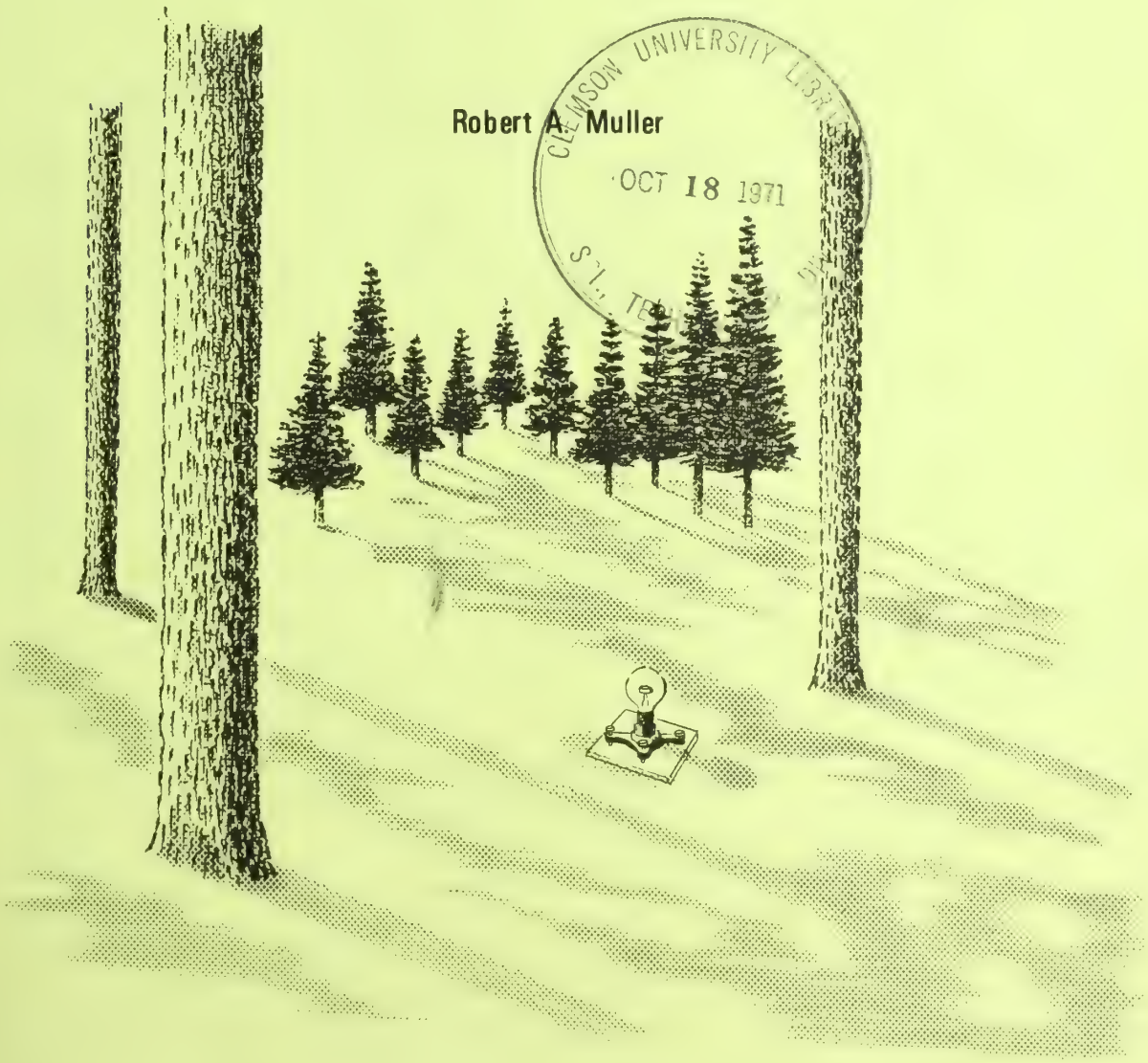
. BOX 245, BERKELEY, CALIFORNIA 94701

# TRANSMISSION COMPONENTS OF SOLAR RADIATION

## in pine stands in relation to climatic and stand variables



Robert A. Muller

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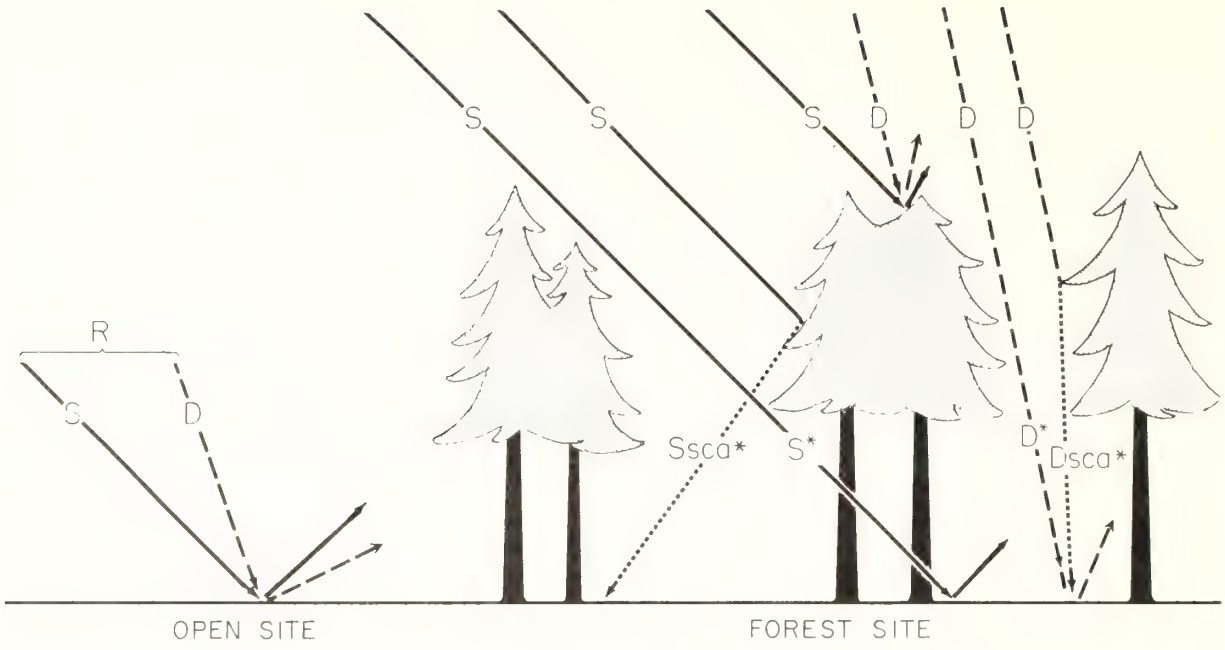


Figure 1—*Components of shortwave radiation budgets. Incoming solar radiation R consists of direct, S, and diffuse, D, radiation downward. Within the stand, direct, S* and diffuse, D* radiation penetrates through crown openings to the floor. Crown biomass scatters some direct, Ssca*, and diffuse, Dsca*, radiation downward to the forest floor. (The asterisk designates transmitted radiation measured under the crowns. The sum of diffuse radiation under the crowns is Dt*.)*

To represent the most dense crown and stand conditions, a stand of Monterey pine *(Pinus radiata* D. Don*)* located in the Berkeley Hills, Berkeley, California, was chosen. This stand was planted for watershed protection in the 1930's.

A ponderosa pine *(Pinus ponderosa* Laws.*)* plantation at the Institute of Forest Genetics, Placerville, California, was selected to represent the more open ponderosa pine stands characteristic of the intermediate western slopes of the central Sierra Nevada. Callaham and Liddicoet (1961) have reported details of the management program for this plantation. During the transmission measurements, half of the trees were removed; measurements were obtained both before and after this treatment.

The third stand, composed primarily of lodgepole pine *(Pinus contorta* Dougl.*)* intermixed with a few western white pines and firs, lies near Soda Springs, California, at an elevation of about 7,000 feet in the central Sierra Nevada west of Donner Pass. It was cut over in the 1800's, and a few large firs taller than 50 feet are remnants of the earlier forest.

Square plots were located so that they would be away from the edge effects of the margins of each stand, with no large crown openings directly overhead. Within each plot transmission was sampled by nine Eppley pyranometers.[1] At the ponderosa pine plantation the trees were planted in a square pattern with an 8- by 8-foot spacing between trees. For this plantation site, a plot size with side dimensions of 30 feet was chosen so that the nine pyranometers could be arranged in a square grid of rows and columns of three with an identical spacing of 8 feet.

At the Monterey pine stand, tree spacing was much less regular, and distances between trees were greater than that at the ponderosa pine plantation. To sample much of the transmission variability between trees within the plot, a square plot 50 feet on a side was selected. Within this plot the nine pyranometers were arranged in rows and columns of three, but this time with 15 feet between sensors. Because the trees were quite crowded at the lodgepole pine plot, a plot size of 30 feet on a side was used.

[1]Trade names and commercial products or enterprises are mentioned solely for necessary information. No endorsement by the U.S. Department of Agriculture is implied.

## Zones of Stand Influence

To explore the relationships among transmission, solar altitude, stand biomass, and species, the concept of a "zone of stand influence" is useful. The area of the crowns through which sunflecks are transmitted is not usually overhead, but, instead, at some horizontal distance from the plot along the solar azimuth. Only those trees along the solar azimuth which can influence transmission of solar radiation to the plot in an hour are important.

In order for a pyranometer to record a full-intensity sunfleck in the transmission plot, the entire sensing surface must "see" the entire solar disk. The diameter of the sensing element of the Eppley pyranometer is 1.125 inches and the apparent angular diameter of the sun is 32 minutes or 0.53 degree. If the crown is taken as a plane without depth 50 feet above the sensor, and if diffraction effects are ignored, then a full-intensity sunfleck requires a crown opening slightly more than 6 inches in diameter when the sun is directly overhead. For a solar altitude of 30°, the direct solar beam would have to pass through a crown opening with a minimum diameter at the upper surface of the crown of nearly 12 inches; the projection of the path on the ground would extend outward nearly 100 feet along the direction of the solar azimuth. Any tree along the sun's azimuth out to about 100 feet from the sensor could intercept direct solar radiation.

Each pyranometer records only a miniscule sample of transmission in the plot. An estimate of mean hourly transmission at the plot is based on the hourly means of all nine sensors.

To provide an index of stand biomass over and around the plots, stem density in inches per acre and basal area per acre were both measured. There is a different index of crown biomass for each hour of measurement, and the zone of stand influence depends on mean solar altitude and azimuth during the hour.

The path of the direct solar beam p through the stand to a sensor is given by equation (1), where A equals solar altitude, and h equals the height of the upper crowns. The horizontal distance out from the sensor, or the length of the zone of stand influence, is given by equation (2). If the crown and trunk space are assumed to be 50 feet thick, and solar altitude is taken at 33°, the path length p is 91.7 feet, and the length of the zone of stand influence $z$ extends outward horizontally for 77 feet.

$$p = h/\sin A \quad (1)$$

$$z = h/\tan A \quad (2)$$

The zone of stand influence in the Monterey pine stand pivots around pyranometer 5 in the center of the transmission plot *(fig. 2)*. The long axis of each zone of stand influence is oriented along the mean solar azimuth for the hour. For 0900-1000 hours, February 28, mean solar azimuth is 140° and mean

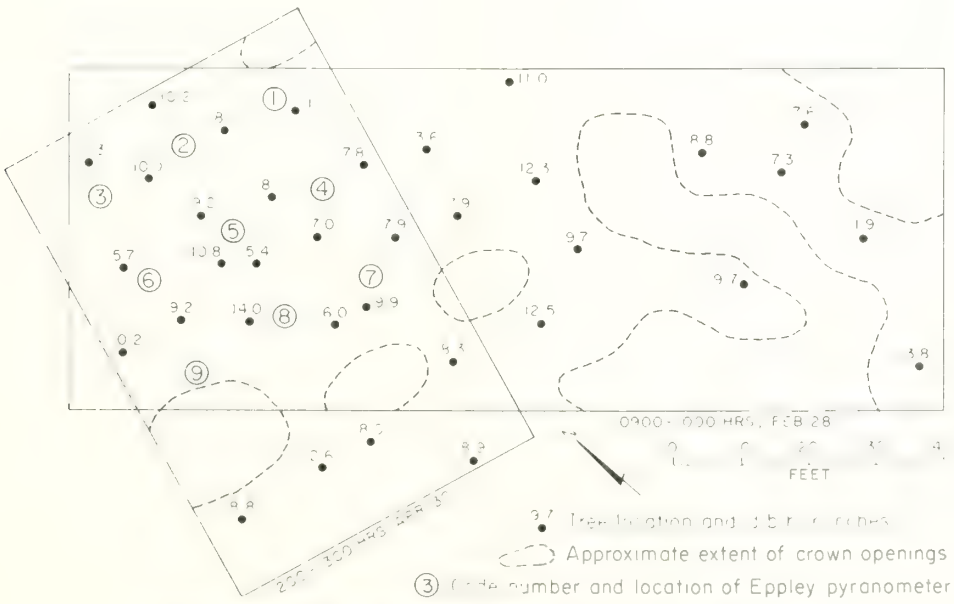


Figure 2 *Zones of stand influence in the Monterey pine stand.*

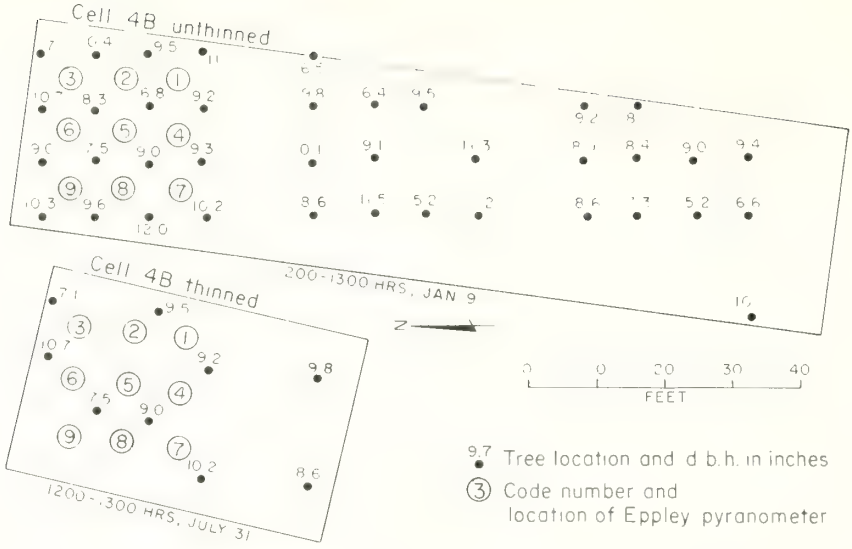
Cell 4B unthinned
1200-1300 HRS, JAN 9
Cell 4B thinned
1200-1300 HRS, JULY 31
N
0 0 20 30 40
FEET
9.7 Tree location and d b.h. in inches
③ Code number and location of Eppley pyranometer

Figure 3—*Zones of stand influence in the ponderosa pine plantation.*

solar altitude is 33°.[2] From the center (pyranometer 5), the transmission plot extends 25 feet along the azimuth of 140°, 25 feet in the opposite direction (azimuth of 320°), and 25 feet out on each side at right angles from the azimuth of 140°; this accounts for the square transmission plot 50 feet on a side. To account for biomass affecting transmission over the entire plot, the zone of stand influence extends the additional 77 feet along the azimuth of 140°. Hence, the total zone of stand influence is a rectangle 127 feet long and 50 feet wide, and its total area is 6,350 square feet. For 1200-1300 hours on April 30, mean solar altitude is 66° and mean solar azimuth is 200°; hence the zone of stand influence is 50 by 72 feet or 3,600 square feet.

## Stand Parameters

From the map of the stand, stand parameters can be summed for each zone of stand influence on an hourly basis. In *figure 2* there were 31 trees in the zone of stand influence for 0900-1000 hours; the sum of stem diameters was 296.3 inches and the sum of basal areas was 16.7 square feet. Since the zone of stand influence is 6,350 square feet, stem density is estimated at 1,985 inches per acre and basal area at 115 square feet per acre. Similarly, there were 23 trees with a stem density of 218.5 inches and a basal area of 12.3 square feet in the zone of stand influence for 1200-1300 hours on April 30. The area is 3,600 square feet. Hence, for this zone of stand influence, stem density is estimated at 2,644 inches per acre and basal area at 149 square feet per acre. In winter the edge of the stand has some effect near noon, when the sun is in the south at low solar altitudes *(fig. 2)*.

The ponderosa pine plantation at Placerville was divided into square cells, each having 16 trees *(fig. 3)*. Between each cell were 16-foot-wide corridors at right angles to each other.

The first example, 1200-1300 hours, January 9, represents the zone of stand influence prior to thinning *(fig. 3)*. Stem density was 4,050 inches per acre and basal area 200 square feet per acre. The second example shows stand biomass soon after thinning when half of the trees were removed. For 1200-1300 hours, July 31, stem density was about 2,400 inches per acre and basal area about 120 square feet per acre. Transmission measurements soon after thinning were somewhat higher than they would be after the crowns of the remaining pines responded fully to the more open conditions.

The lodgepole pine stand was a more irregular stand, with occasional old firs intermixed with the lodgepole pine *(fig. 4)*. For the zone of stand influence for 0900-1000 hours, May 12, stem density amounted to 7,900 inches per acre and basal area was 450 square feet per acre, the largest index of biomass at the three sites. A small opening was included in the zone of stand influence for 1300-1400 hours, May 12; stem density amounted to 5,050 inches per acre, and basal area to 275 square feet per acre. Hence, in

[2]Estimates of mean solar altitude and azimuth can be obtained from equations given in *Smithsonian meteorological tables*, R. J. List, ed. Washington, D. C., 1951, p. 497.

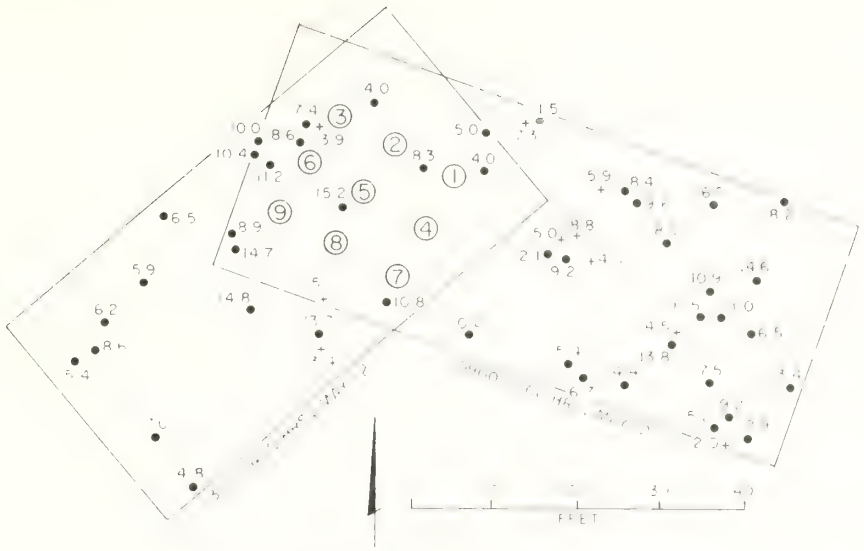


Figure 4— *Zones of stand influence in the lodgepole pine stand.*

terms of these particular stand parameters, the lodgepole pine stand represented the most dense conditions.

## Data Collection

For analysis of relationships, measurements of transmission were restricted to clear sky conditions when the solar radiation flux downward changes slowly and systematically. Instantaneous measurements of the millivolt output of each pyranometer were obtained by means of a portable millivolt balancing potentiometer.[3] By use of a junction box, instantaneous measurements of the transmission of solar radiation (R*)[4] by each of the nine Eppley pyranometers within the transmission plot were completed in about 3 minutes. During an hour, transmission (R*) was sampled by the nine pyranometers at 10-minute intervals so that an hourly transmission mean for the plot is based on 54 samples.

The flux of diffuse solar radiation under the stand (Dt*) including direct solar radiation scattered downward by crowns (Dsca*), was sampled by shading the same pyranometers from the direct solar beam. Four-inch aluminum disks were held about 2 feet from the sensor so that the bulb of each sensor was shielded from the direct solar beam (S*). When allowances were made for each sensor to stabilize for shielded conditions, it was possible to measure the millivolt output of all nine sensors in 5 minutes or less. Diffuse solar radiation under the stand (Dt*) was not so variable as direct solar radiation (S*), and hourly means of diffuse solar radiation for the plot were based on measurement sequences at 20- or 30-minute intervals.

Solar radiation in the atmosphere (R) was measured at nearby open sites by one or two Kipp and Zonen solarimeters. The millivolt output of the solarimeters was measured with a second portable balancing millivolt potentiometer on a 10-minute interval;[5] hourly means for insolation (R) above the transmission plots were calculated from these data.

[3]Factory calibration of the Eppley pyranometers was checked occasionally by comparisons of instantaneous millivolt outputs and factory calibration coefficients between sensors during clear sky conditions over periods ranging between 4 and 10 hours. The extreme range was ± 5 percent, and for most circumstances the agreement among sensors was ± 2 percent. The variability among the 10-junction Eppley pyranometers was not systematic usually.

[4]The asterisk is used to symbolize transmitted radiation measured under tree crowns. For a discussion of radiation and energy balance components in forest, see Miller (1965).

[5]During calibration checks, the instantaneous measurements obtained from the solarimeters were found to agree with the Eppley pyranometers within a range of ± 5 percent.

Table 1—*Transmission components of Monterey pine stand, February 25, 1964, by hours (P.s.t.)*

| Component | 8-9 | 9-10 | 10-11 | 11-12 | 12-13 | 13-14 | 14-15 | 15-16 | Total |
|---|---|---|---|---|---|---|---|---|---|
| | *Langleys per hour* | | | | | | | | |
| S | 24.6 | 40.8 | 53.0 | 59.3 | 60.9 | 56.6 | 47.6 | 37.1 | 379.9 |
| S* | .6 | 1.0 | 1.0 | 2.3 | 1.5 | 1.1 | 0.2 | 0.1 | 7.8 |
| D | 4.1 | 5.0 | 5.5 | 5.8 | 5.7 | 5.6 | 5.4 | 4.5 | 41.6 |
| Dt* | .6 | .9 | 1.2 | 1.2 | 1.2 | 1.0 | .7 | .4 | 7.2 |
| D*[1] | .2 | .2 | .2 | .2 | .2 | .2 | .2 | .2 | 1.6 |
| Dt* -D* | .4 | .7 | 1.0 | 1.0 | 1.0 | .8 | .5 | .2 | 5.6 |
| Ssca*[2] | .3 | .6 | .9 | .9 | .9 | .7 | .4 | .2 | 4.9 |
| Dsca* | .1 | .1 | .1 | .1 | .1 | .1 | .1 | – | .7 |
| | *Percent* | | | | | | | | |
| S*/S | 2 | 2 | 2 | 4 | 2 | 2 | <1 | <1 | 2 |
| D*/D | 15 | 18 | 22 | 21 | 21 | 18 | 13 | 9 | 17 |

[1]Assumed D*/D = 4 percent.

[2]Assumed Dt*–D* = Ssca* + Dsca* and Dsca*/D = Ssca*/S.

to 11 percent of insolation (R). The ratio (Dt*/D) about noon reached its maximum—slightly more than 20 percent. This ratio was nearly ten times greater than (S*/S), and included the scattering effect of the crowns on direct solar radiation (Ssca*) in addition to transmission and scattering of diffuse solar radiation (D* and Dsca*) in the atmosphere.

These three components of transmitted diffuse radiation (Dt*) can be separated approximately by two reasonable assumptions. Diffuse radiation in the atmosphere comes primarily from regions near the sun and the zenith. With low solar altitudes, on February 25, the Monterey pine transmitted only about 2 to 4 percent of the direct solar beam (S*/S). Since the path length of diffuse solar radiation through the crowns should be, on the average, less than the path length of direct solar radiation on a day with low solar altitudes, it seems reasonable to assume that no more than 4 percent of the diffuse solar radiation in the atmosphere (D) was transmitted through the crown openings (D*). The assumption may represent a slight underestimate near solar noon and a slight overestimate near sunrise and sunset. This assumption of 4 percent transmission is used to obtain the estimate of transmission of diffuse radiation (D*) which amounted to only about 0.2 ly/hour during each of the measurement hours *(table 1)*.

The value of (Dt*-D*) is the remaining proportion of diffuse radiation under the stand not accounted for by transmission of diffuse radiation (D*) *(table 1)*. This remainder represents the downward scattering of both direct and diffuse radiation in the atmosphere by stand biomass. Assume now that the downward scattering effect of the Monterey pine crowns is relatively equal with respect to direct and diffuse solar radiation in the atmosphere. The remainder (Dt*/D*) can be apportioned to downward scattering of direct (Ssca*) and diffuse (Dsca*) solar radiation according to the relative downward flux of direct (S) and diffuse (D) solar radiation in the atmosphere. Hence, for this clear day, between 50 and 75 percent of the diffuse solar radiation under the stand (Dt*) originated as direct solar radiation. Even if the scattered diffuse solar radiation (Dsca*) is underestimated, diffuse solar radiation in the atmosphere is so small during clear days that any underestimate is of little consequence. The dense foliage of the crowns and the 80- to 100-percent crown closure exclude almost all of the direct and diffuse solar radiation alike.

A similar analysis of transmission components for the ponderosa pine plantation during the clear day, April 29, 1964, about 1 year after the thinning treatment, was made *(table 2)*. The remaining pines had not as yet filled in vacant crown space, and canopy closure was estimated to range between 40 to 60 percent.

Since solar altitudes on April 29 were higher than on February 25, 1964, incoming direct and diffuse solar radiation at the ponderosa pine plantation were considerably greater. An upslope mountain breeze occasionally drew a thin plume of smoke over the site from a sawmill several miles away, and the slightly irregular hourly trace of diffuse solar radiation (D) was probably a consequence of the smoke. Between 1200-1300 hours the remaining pines in the zone of

Table 2—*Transmission components of ponderosa pine plantation, April 29, 1964, by hours (P.s.t.)*

| Component | 8-9 | 9-10 | 10-11 | 11-12 | 12-13 | 13-14 | 14-15 | 15-16 | 16-17 | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | *Langleys per hour* | | | | | | | | | |
| S | 42.3 | 61.4 | 70.8 | 76.5 | 75.9 | 70.3 | 60.2 | 47.0 | 31.4 | 535.8 |
| S* | 19.6 | 26.4 | 32.0 | 30.3 | 18.4 | 23.6 | 23.9 | 9.7 | 3.8 | 187.7 |
| D | 8.9 | 9.8 | 10.0 | 9.2 | 8.2 | 7.9 | 8.7 | 8.0 | 6.6 | 77.3 |
| Dt* | 7.6 | 8.2 | 8.1 | 8.0 | 7.9 | 7.9 | 7.9 | 6.6 | 4.9 | 67.1 |
| D* | 3.1 | 3.9 | 4.5 | 4.1 | 3.7 | 3.6 | 3.5 | 2.8 | 2.0 | 31.2 |
| Dt*–D* | 4.5 | 4.3 | 3.6 | 3.9 | 4.2 | 4.3 | 4.4 | 3.8 | 2.9 | 35.9 |
| Ssca*[1] | 3.7 | 3.7 | 3.2 | 3.5 | 3.8 | 3.9 | 3.9 | 3.3 | 2.4 | 31.4 |
| Dsca* | .8 | .6 | .4 | .4 | .4 | .4 | .5 | .5 | .5 | 4.5 |
| | *Percent* | | | | | | | | | |
| S*/S | 46 | 43 | 45 | 40 | 24 | 34 | 40 | 21 | 12 | 35 |
| Dt*/D | 85 | 84 | 81 | 87 | 96 | 100 | 91 | 82 | 74 | 87 |
| D*/D[2] | 35 | 40 | 45 | 45 | 45 | 45 | 40 | 35 | 30 | |

[1]Assumed Dt*–D* = Ssca* + Dsca* and Dsca*/D = Ssca*/S.

[2]Assumed.

stand influence reduced the transmission of direct solar radiation considerably.

In this open stand the ratio of transmitted diffuse radiation to diffuse radiation in the atmosphere ((Dt*/D), ranged between 74 and 100 percent. Diffuse radiation within the open plantation was nearly as great as diffuse radiation in the atmosphere. The transmission of direct solar radiation (S*/S) reached a maximum of about 45 percent. Therefore, the transmission of diffuse radiation (D*/D) was assumed to average 45 percent during the 4-hour period centered at noon, and to decrease gradually toward sunrise and sunset as the path length of diffuse radiation in the atmosphere through crown space gradually increased *(table 2)*.

Finally, the transmission components during the clear day, May 12, 1964, for the lodgepole pine stand were analyzed *(table 3)*. High solar altitudes and a 7,000-foot elevation resulted in a very strong flux of direct solar radiation. A few cumulus clouds upslope and to the east increased diffuse radiation at the site because of reflection downward early in the afternoon. Surprisingly, this increase of atmospheric diffuse radiation was not detected as transmitted diffuse radiation.

Table 3—*Transmission components of lodgepole pine stand, May 12, 1964, by hours (P.s.t.)*

| Component | 6-7 | 7-8 | 8-9 | 9-10 | 10-11 | 11-12 | 12-13 | 13-14 | 14-15 | 15-16 | 16-17 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Langleys per hour* | | | | | | | | | | | |
| S | 23.8 | 41.1 | 60.2 | 74.1 | 82.7 | 86.4 | 85.4 | 83.8 | 67.8 | 56.5 | 38.2 | 700.0 |
| S* | 0.1 | 0.8 | 1.6 | 9.5 | 22.1 | 22.0 | 15.7 | 11.2 | 4.4 | 2.5 | .6 | 90.5 |
| D | 4.2 | 4.9 | 5.8 | 5.9 | 6.0 | 6.2 | 6.1 | 9.8 | 7.2 | 5.0 | 5.5 | 66.6 |
| Dt* | 1.5 | 2.4 | 2.8 | 4.4 | 4.8 | 5.5 | 4.8 | 4.9 | 3.2 | 2.0 | 1.2 | 37.5 |
| D* | .8 | 1.0 | 1.4 | 1.5 | 1.8 | 1.9 | 1.8 | 2.9 | 1.8 | 1.2 | 1.1 | 17.2 |
| Dt*–D* | .7 | 1.4 | 1.4 | 2.9 | 3.0 | 3.6 | 3.0 | 2.0 | 1.4 | .8 | .1 | 20.3 |
| Ssca*[1] | .6 | 1.3 | 1.3 | 2.7 | 2.8 | 3.4 | 2.8 | 1.8 | 1.3 | .7 | .1 | 18.8 |
| Dsca* | .1 | .1 | .1 | .2 | .2 | .2 | .2 | .2 | .1 | .1 | – | 1.5 |
| | *Percent* | | | | | | | | | | | |
| S*/S | <1 | 2 | 3 | 13 | 27 | 25 | 18 | 13 | 6 | 4 | 2 | 13 |
| Dt*/D | 36 | 49 | 48 | 74 | 80 | 89 | 79 | 50 | 44 | 40 | 22 | 56 |
| D*/D[2] | 20 | 20 | 25 | 25 | 30 | 30 | 30 | 30 | 25 | 25 | 20 | |

[1]Assumed Dt*–D* = Ssca* + Dsca* and Dsca*/D = Ssca*/S.

[2]Assumed.

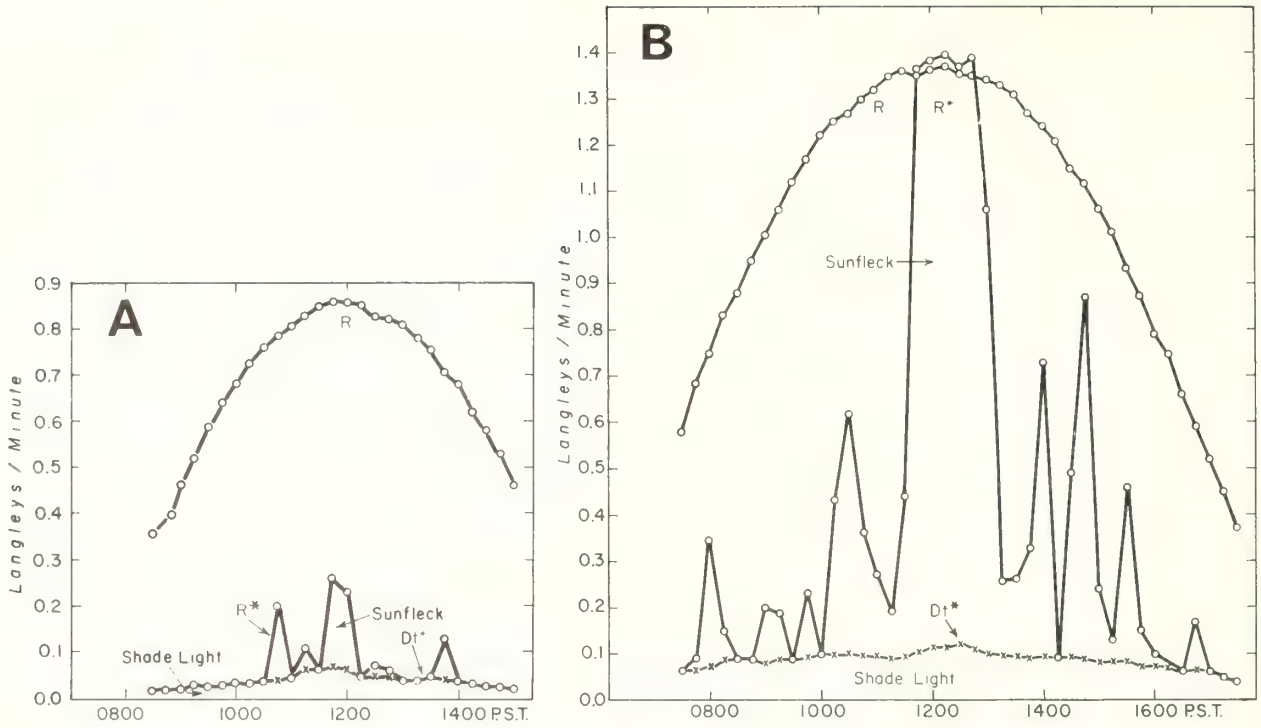


Figure 8.—*Transmission components measured by Eppley pyranometer No. 1, at a ponderosa pine plantation. A, before thinning, on a clear day, January 11, 1963. B, after thinning, on a clear day, August 1, 1963; level of diffuse solar radiation (Dt*) was much higher than that before thinning. R = insolation; D* = insolation under crowns; Dt* = diffuse solar radiation under crowns.*

the similar proportion for direct solar radiation (S*/S). Hence, the sunfleck must have included downward scattering from nearby crowns (Ssca* + Dsca*). Sunflecks at or slightly above full intensity were not uncommon in Cells 3B and 4B of the plantation after thinning.

## CONCLUSIONS

Most investigations of transmission appear to be biased toward summer-season maximum transmission rates. Clearly, transmission is related to daily and seasonal regimes of solar altitude, and comparative analyses among sites and species need to take this into account. At the same site, direct and diffuse solar radiation is probably not transmitted in equal proportions. For meaningful analysis, data collection should be restricted to either clear or cloudy conditions.

In dense stands, at middle latitudes, sunflecks account for a large proportion of the solar radiation reaching the forest floor. On the basis of the sampling of transmission during clear sky conditions at the three sites, it seems reasonable to set down the following generalizations concerning sunflecks as measured by the pyranometer:

1. The precise occurrence of sunflecks at a point on the forest floor is the consequence of the unique distribution of crown biomass within a relatively large area to the east, south, and west of the point—the zone of stand influence; the crown directly over the sensor is not always the most significant biomass;

2. Because of the daily and seasonal regimes of solar altitude and solar azimuth, sunfleck contributions at a point cannot be predicted from a few random measurements over the year;

3. Because of downward scattering from adjacent crowns, sunfleck intensity may occasionally exceed by rather small amounts the concurrent intensity of insolation;

4. Because of the wide range of sunfleck intensity,

direct solar radiation transmitted through crowns cannot be estimated on the basis of the areal distribution of sunflecks alone;

5. A rigorous analysis of radiation components within a forest stand probably requires an intensive sampling scheme for estimation of transmission of sunflecks for short but seasonally representative time units and

6. Biological activity under the crown must be adapted to the low flux of diffuse solar radiation (Dt*), but at the same time be adapted to sudden impulses of solar radiation associated with the passage of sunflecks which may at times equal or slightly exceed insolation.

## SUMMARY


Muller, Robert A.

1971. **Transmission components of solar radiation in pine stands in relation to climatic and stand variables.** Berkeley, Calif., Pacific SW. Forest & Range Exp. Sta. 13 p., illus (USDA Forest Serv. Res. Paper PSW-71)

*Oxford:* 111.211–015.24:111.86(794)[+ 174.7 *Pinus radiata* + 174.7 *Pinus ponderosa* + 174.7 *Pinus contorta*].

*Retrieval Terms:* pine forests; California; solar energy regime; bioclimatology; pyranometry.

Transmission of solar radiation in forest stands refers to the ratio of solar radiation under crowns to solar radiation in the atmosphere. Data from other studies are not directly comparable because investigations have been carried out over a wide range of solar climates and because of largely unsatisfactory measures of stand biomass which directly produce attenuation of the solar beam downward through crowns.

In a new approach, this study relates the transmission ratio to mean hourly solar altitude and to an index of stand biomass within zones oriented along mean solar azimuths. For three pine species in California, the relationship between solar altitude and transmission was curvilinear during clear sky conditions—transmission increased sharply at higher solar altitudes. Transmission was also inversely related to the index of stand biomass, and in addition, differences probably attributable to crown characteristics of each species were considerable.

The magnitude of the pathways by which direct and diffuse radiation penetrate through the crowns was estimated analytically by means of measurements of direct and diffuse solar radiation by standardized sensors and also by several reasonable assumptions. The data suggest that for clear sky conditions at lower and middle latitudes, sunflecks account for more than half of the transmission even in dense stands. Sunfleck intensity on the forest floor was highly variable; indeed, the intensity of a few sunflecks exceeded slightly solar radiation in the atmosphere because of the downward scattering effects of the crowns.


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Muller, Robert A.

1971. **Transmission components of solar radiation in pine stands in relation to climatic and stand variables.** Berkeley, Calif., Pacific SW. Forest & Range Exp. Sta. 13 p., illus. (USDA Forest Serv. Res. Paper PSW-71)

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PACIFIC SOUTHWEST
Forest and Range
Experiment Station

# Population Density of Western Spruce Budworm as Related to Stand Characteristics in the Bitterroot National Forest

Carroll B. Williams, Jr. Patrick J. Shea Gerald S. Walton

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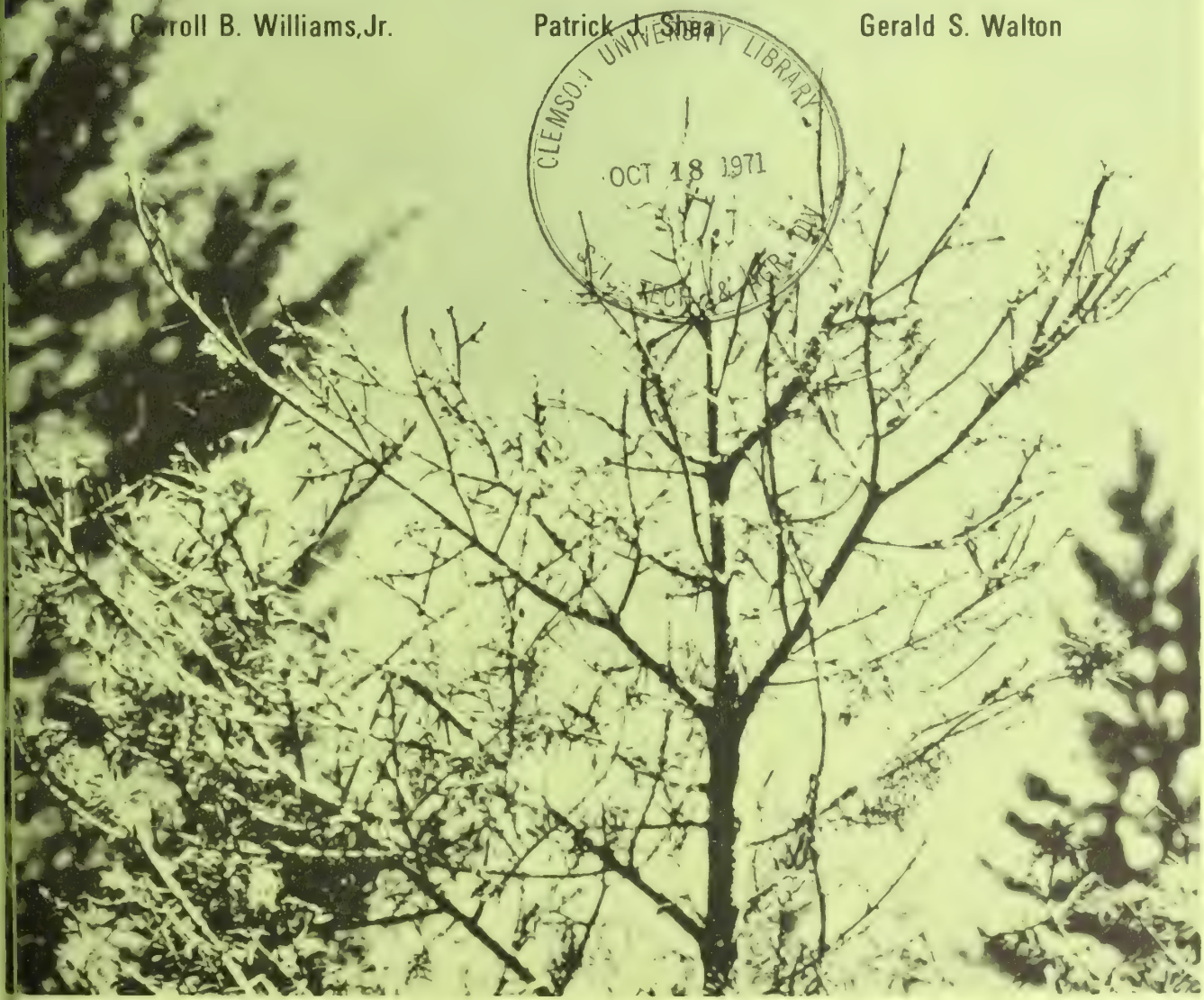

USDA FOREST SERVICE RESEARCH PAPER PSW- 72 /1971

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## The Authors

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Damage by the western spruce budworm *(Choristoneura occidentalis* Freeman*)* is widespread throughout the Western United States. The main host trees are Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco*)*—usually the most common—Engelmann spruce *(Picea engelmannii* Parry*)*, and the true firs *(Abies* spp.*)*. High budworm populations severely defoliate the trees, reducing growth—and trees often die after several years of defoliation. True firs are particularly vulnerable to defoliation damage. In eastern Oregon, grand fir *(A. grandis* [Dougl.] Lindl.*)* suffer heavier damage than associated Douglas-fir (Williams 1966, 1967).

Site and growth conditions affect mortality and damage to the trees. Turner (1952) examined mortality of balsam fir *(A. balsamea* [L.] Mill*)* caused by the spruce budworm *(C. fumiferana* Clemens*)* in Ontario. He found that percentage mortality of fir increased as basal area of fir per acre increased. Shephard (1959) reported that more defoliation damage by the 2-year-cycle budworm *(C. biennis* Freeman*)* occurred in Englemann spruce-subalpine fir forest stands growing on dry, poor sites than in stands growing on relatively moist, more productive sites in the Canadian Rocky Mountains.

On the Bitterroot Range in Montana, we found only a few Douglas-fir trees growing near streams or in the open stands on the south-to-west facing slopes that had been killed by defoliation. We observed much greater mortality in the dense, small, heavily defoliated sawtimber stands of Douglas-fir growing on the upper portions of the north-facing slopes. Competition for water in these dense stands appeared to contribute to mortality of the defoliated trees.

Forest entomologists have devised various schemes that attempt to describe, group, or classify the variations in current defoliation and cumulative damage caused by defoliation and to show their relation to reductions in tree growth (Church 1949; Williams 1967). Many of these schemes have not related variation in damage to actual insect population levels. If they are strongly related to budworm population density then they can be used as indirect measures to classify population levels as well as to describe damage and indicate reductions in individual tree growth.

To reduce their sampling work forest entomologists have assumed that the average population density of the western spruce budworm is situated at mid-crown in infested trees. This assumption is based on the population distribution of the spruce budworm within the crowns of balsam fir in New Brunswick as reported by Morris (1955). This assumption must be checked for the situation in the West since the population distribution of the western spruce budworm in tree crowns may differ among its host tree species. If the assumption is false then sampling only the mid-crowns of host trees may give biased information.

Forest managers might be able to reduce the frequency and severity of western spruce budworm outbreaks and damage by regulating stand and tree conditions that contribute to high population levels. Research is needed to identify conditions that can be manipulated by cutting and other stand management practices. To see if there is a relationship between levels of western spruce budworm populations and forest stand and tree conditions we related budworm density to eight characteristics, ranging from tree species to the study areas, on four budworm-infested drainages in the Bitterroot National Forest in Montana.

This paper reports on the study and offers some suggestions on damage survey and forest management based on the results.

# STUDY AREAS

A series of plots were laid out in four V-shaped drainages that are tributary to the west fork of the Bitterroot River about 50 miles southwest of Hamilton, Montana. The four drainages range from 1,000 to 1,200 acres. *C. occidentalis* was found on Douglas-fir, Engelmann spruce, and subalpine fir *(Abies lasiocarpa* [Hook] Nutt.*)*. In an earlier study (Williams and Walton 1968), two of the drainages (Tough Creek and Mud Creek) were aerially sprayed with insecticides and the remaining two drainages (One-Two and Blue Joint Creeks) were used as check areas. The budworm population data used in the study reported here were obtained from the pre-spray sampling work, which was carried out in early July when most of the population was in the fifth instar.

Three stand types predominate in each of the four drainages: (1) open stands of large ponderosa pine with a mixed pine and Douglas-fir understory on the south-to-southwestern slopes; (2) dense mixed stands of scattered large pine and Douglas-fir with a predominantly Douglas-fir understory on the northeast-facing slopes; and (3) dense stands of large Engelmann spruce, subalpine fir, and Douglas-fir on the moist to wet flood plains. Study plots established in each type consisted of at least four Douglas-fir trees and up to four each of subalpine fir and Engelmann spruce trees.

Four study plots were established in Blue Joint Creek drainage and eight plots in each of the remaining three drainages. Two plots were on the flood plain; two on the exposed, southwest-facing slopes; and the remaining four on the northeast-facing slopes for Tough, Mud, and One-Two Creek drainages. At Blue Joint Creek, two plots were on the flood plain and one each on the south-facing and north-facing slopes.

We found subtle differences in vegetation composition among the four study areas, with Blue Joint Creek having the greatest difference. Generally, Douglas-firs were the most numerous trees in the stands, although ponderosa pines were the largest trees, particulary on the dry, west-facing plots. Subalpine fir and Engelmann spruce were generally restricted to the moist and sheltered situations, reaching their best development with Douglas-fir on the flood-plain plots. Aspen *(Populus tremuloidea* Michx.*)* and cottonwood *(P. trichocarpa* T. and G.*)* were restricted to wet areas in Blue Joint Creek.

Although the understory plant unions were complex, the vegetation on the four drainages appeared to fit Daubenmire's (1952) Douglas-fir/ninebark habitat type. The tree reproduction is mainly Douglas-fir. Clearly, forest succession in the four drainages, in the absence of fire, is rapidly going from ponderosa pine to Douglas-fir, a more budworm-susceptible forest.

# METHODS

The relation between manageable aspects of the forest environment and high levels of insect density was studied through data gathered in the field and subjected to analysis of variance. To ensure that the results could be unambiguously interpreted, only main effect variables were included in a model. Further, data were analyzed for site and tree variables which could be modified by forest management. Besides counting insects, we measured defoliation and damage. These variables, although dependent on density, were included in the analysis so that the degree of dependence could be determined. These variables can be observed by the forester and might be useful to him in making management decisions.

The dependent variable used in the analysis of variance was $\log_e ((1+ C)/A)$, in which $C$ was the insect count and $A$ the surface area of the branch sample. The independent variables consisted of one concomitant variable (plot basal area) and eight sets of classification variables: (1) tree species; (2) crown level; (3 and 4) 10 levels of current and total defoliation (0-1-, 10-20...,90-100 percent) estimated for each tree; (5) four intensities of cumulative damage (damage classes) estimated for each tree; (6) five levels of bud defoliation on each 15-inch twig; (7) five levels of total twig defoliation for each 15-inch twig; and (8) study area.

We recognize that the defoliation and damage variables could also be used as dependent variables in an analysis, since they are in themselves indicators of population density. We found it more practical, however, to center the analysis on density.

We estimated 38 parameters, including the population mean, from 1,098 observations. One problem with this analysis is that, with 1,060 degrees of freedom available for estimating the mean-squared error, tests for significance are so powerful they detect differences too small to be of practical interest. This limitation should be kept in mind in the discussion that follows.

# RESULTS

Budworm populations are notoriously dynamic, but the study data are apparently representative, since our analyses revealed associations with stand factors and damage conditions similar to those found in other forest types in North America with other *Choristoneura* sp. These associations had not been previously examined for *C. occidentalis* in Douglas-fir forests. Therefore, the information from the study reported here should be valuable to western entomologists and forest managers even though only 1 year's data were available for analysis.

Plot basal area, tree species, and crown level were related to population densities at a significance level of less than 0.005 percent *(table 1)*. The implication with regard to basal area is that higher budworm densities occurred on open-grown trees. Budworm populations were generally higher on subalpine fir than on Douglas-fir and Engelmann spruce. Population densities were highest in the upper third of tree crowns and lowest in the lower third. Generally population densities at mid-crown approximated the average for the tree (see estimated coefficients for tree crown *[table 1]*). The fact that no difference in budworm population density was detected between areas (significance level over 5 percent *[table 1]*) is noteworthy in that it implies that the only differences between the drainages were explained by the other variables used in the analysis. However, the areas are so close together that noticeable regional effects would not be expected.

Shoot defoliation and current year's defoliation were also related to budworm density at the 0.005 percent level. Up to a point, more budworms were found on the more heavily defoliated branches than elsewhere *(table 1)*. Total cumulative defoliation and damage class estimates have little practical relevance to current budworm population density, although the differences we detected are real. Since these variables include previous as well as present damage, they are more closely related to total annual insect population densities for the entire outbreak to date than to current population density. Estimates of defoliation of twigs proved to be of marginal value.

# DISCUSSION

The analyses show strong relationships between western spruce budworm population densities and various methods of classifying defoliations and damage caused by this insect. Significant relationships were logically expected between current population densities and those classifications describing current defoliations. However, what was surprising were the highly significant relationships between current populations densities and total (cumulative) damage evaluations.

The analyses also showed that the number of classes for current year's and total defoliation can be reduced by combining the several classes bracketed in *table 1*. Tables can be prepared collating the mean, standard error of the mean, and range of population density data with the various classes of the revised defoliation and damage classification schemes. These revised classifications can be rechecked in the field at various places and times to determine the range of their applicabilities in damage surveys.

Douglas-fir was the most abundant host tree on the study areas and comprised most of the sample trees. The population distribution of the western spruce budworm within the crowns of sample trees reflects the situation in Douglas-fir *(table 1)*. The estimated coefficients indicate the average population density is approximately at mid-crown.

The population densities on subalpine fir shifted downward from the top third of the crown. This condition was probably due to lack of feeding sites at the time of sampling because of the almost complete defoliation and stem dieback observed on the top portions of subalpine fir crowns. Engelmann spruce trees had relatively low budworm populations, and no conclusions can be made at this time on population distribution in spruce trees.

The remaining discussion will concern the relationships between budworm population levels and various stand and environmental factors that influence budworm survival and tree mortality.

Much of the work to date on the population dynamics of the spruce budworm species complex has been done by various workers in eastern Canada with spruce budworm and by Shephard (1959) with the 2-year cycle budworm *(C. biennis* Free.*)* in Alberta. In general, they found that weather and character of the forest are the two major factors responsible for development of spruce budworm outbreaks. Outbreaks have tended to follow periods of relatively dry weather during the larval stage in forested areas with

Table 1—*Analysis of variance related to density of western budworm population, Bitterroot National Forest, Montana, 1965*

| Variable factors and level | Estimated coefficient B | Sum of squared residuals with treatment B's=0[1] | F-Test for B's=0 | Degrees of freedom[2] | Significance of F-Test |
|---|---|---|---|---|---|
| | | | | | *Percent* |
| Plot basal area | -0.03893 | 491.442 | 21.656 | 1 | 0.005 |
| Tree species: | | | | | |
| Subalpine fir | .14872 | 496.825 | | 2 | .005 |
| Douglas-fir | .13240 | | | | |
| Engelmann spruce | -.28112 | | | | |
| Shoot defoliation (pct.): | | | | | |
| 0 - 10 | -.46530 | 513.511 | 17.547 | 4 | .005 |
| 10 - 25 | -.03191 | | | | |
| 25 - 50 | .23892 | | | | |
| 50 - 75 | .18359 | | | | |
| 75 - 100 | .07470 | | | | |
| Tree crown: | | | | | |
| Lower third | -.29167 | 534.042 | 57.687 | 2 | .005 |
| Middle third | .04850 | | | | |
| Upper third | .24317 | | | | |
| Current year's defoliation (pct.): | | | | | |
| Class I 0-10 | -.0036 | 541.984 | 14.762 | 9 | .005 |
| [3] II 10-20 | -.50770 | | | | |
| [3] III 20-30 | -.53147 | | | | |
| IV 30-40 | .08334 | | | | |
| [3] V 40-50 | -.01576 | | | | |
| [3] VI 50-60 | -.06599 | | | | |
| VII 60-70 | -.27972 | | | | |
| VIII 70-80 | .42525 | | | | |
| IX 80-90 | .48678 | | | | |
| X 90-100 | .40563 | | | | |
| Total defoliation (cumulative): | | | | | |
| I 0-10 | -.20958 | 496.877 | 3.731 | 9 | .015 |
| II 10-20 | -.21702 | | | | |
| III 20-30 | .05582 | | | | |
| IV 30-40 | -.10696 | | | | |
| V 40-50 | .07268 | | | | |
| VI 50-60 | .08121 | | | | |
| VII 60-70 | .33303 | | | | |
| VIII 70-80 | .20494 | | | | |
| IX 80-90 | .08935 | | | | |
| X 90-100 | -.30347 | | | | |
| Damage class: | | | | | |
| Class I | .06118 | 486.888 | 3.865 | 3 | .893 |
| II | -.20502 | | | | |
| III | -.32651 | | | | |
| IV | .47035 | | | | |
| Twig defoliation: | | | | | |
| 0 - 10 | -.15290 | 485.834 | 2.318 | 4 | 5.467 |
| 10 - 25 | -.08425 | | | | |
| 25 - 50 | .07790 | | | | |
| 50 - 75 | .04211 | | | | |
| 75 - 100 | .11714 | | | | |
| Areas: | | | | | |
| Tough Creek | .02682 | 482.542 | .676 | 3 | 56.88 |
| Mud Creek | .02550 | | | | |
| One-Two Creek | .01835 | | | | |
| Blue Joint Creek | -.07067 | | | | |

[1]Complete model: 481.621.

[2]Complete model: 1,060.

[3]Bracketed classes may be combined without significant loss of information.

extensive stands of mature and over-mature balsam fir (Balch 1946; Wellington, *et al.* 1950; Morris and Bishop 1951; Graham 1956; Greenbank 1956). Hot dry weather favors larval feeding, development, and survival in all instars more than does cloudy, rainy weather (Wellington 1949, 1950a, 1950b; Greenbank 1956). Because solar radiation directly affects rate of evaporation, any stand characteristic that increases tree crown exposure to solar radiation and thereby reduces the relative humidity surrounding the budworm feeding and resting sites will favor budworm survival.

The study reported here showed that open-grown trees (i.e., those with the greatest crown exposure) supported the greatest western spruce budworm populations. Apparently, the survival of larvae between the bud attack period and pupation (fourth to sixth instars) is increasingly favored with increased exposure to solar radiation. We concluded that defoliation of the tree crown altered the feeding larva's exposure to solar radiation and favored large larval survival up to the point where food shortage occurred. Our findings support observations made elsewhere (Mott 1963).

Although an open stand favors survival of late-instar larvae by providing full crown exposure, it is not favorable for first and second instar larvae. These are dispersed by the wind, the first after hatching, and the second at emergence from hibernation. During dispersal periods, larvae are more likely to land on host trees in a dense stand than in an open stand. The highest mortality of the generation occurs during these dispersal periods (Miller 1958).

Early and late instar larvae would probably have the maximum chance of survival in a stand of essentially even-aged trees, stocked with one or more host species but few nonhost species, and having considerable lateral crown exposure and no large openings. Most Douglas-fir stands east of the Continental Divide in Montana fit this description. Many of them have been infested by high populations of western spruce budworm for many years, and some have suffered high tree mortality.

Douglas-fir is at the eastern limits of its geographical range in eastern Montana. It grows in essentially even-aged stands on sites where soil moisture appears to be limiting. Competition for water affects tree mortality at a given level of budworm defoliation. We examined more than 100 increment cores from trees near Big Timber in eastern Montana. They showed that trees growing in shallow soil on dry knolls died after about 5 years of severe defoliation; those growing on wetter sites endured as much as 40 years of defoliation. Tree mortality in dense stands on dry, rocky slopes was heavy.

Nearly all understory trees in most Douglas-fir stands observed were killed. Larvae dropped on them from adjacent larger trees. The small crowns of understory trees are normally sparsely foliated and cannot support as high a budworm density as larger, more full grown neighbors. Dominant trees win out in the competition for water during the dry summers.

## RECOMMENDATIONS

The results of this study and observations in eastern Montana suggest the following stand management practices to reduce the vulnerability of western forest stands to excessive damage from defoliation by the western spruce budworm:

• *Maintain a stand of thrifty, rapidly growing trees.*

A stand open enough to provide good crown exposure to solar radiation and preclude excessive competition for water is required. Sub-economic weeding and thinning before the stand reaches commercial size may be necessary to meet this need.

Our study showed that trees growing in stands of low basal area (i.e., high crown exposure) generally had higher budworm population densities than trees in very dense stands (low crown exposure). However, these relatively open-grown trees could sustain a high budworm population level and still survive because they are thrifty and they produce many more normal and adventitious buds than trees having less crown exposure growing in dense stands. Although these thrifty trees produce more budworm feeding sites, they can survive and more quickly recover from defoliation than trees with much fewer buds because their food reserves are greater.

Relatively open-grown trees can withstand greater stress from defoliation and survive better than trees which must compete for moisture in dense stands.

• *Reduce the true-fir complement in all budworm susceptible forest stands.*

Budworm density was generally higher on grand fir[1] and subalpine fir in stands where these species

[1]Williams, Carroll B., and Patrick J. Shea. *Trapper Creek Zectran tests 1966.* (Unpubl. rep. on file Pacific SW. Forest & Range Exp. Sta., Berkeley, Calif.)

grow in association with Douglas-fir and Engelmann spruce. Relatively few stands held substantial numbers of mature true firs. These stands were at the higher elevations or on relatively moist sites or both. Consequently, these stands can be logged without difficulty. A diversified forest type should be encouraged to break up continuous canopies of budworm host species.

• *Harvest Douglas-fir and burn cutting units to favor ponderosa pine over all firs in the succeeding stands.*

Wherever feasible ponderosa pine should be encouraged on those sites where it can grow well. In Montana these sites tended to be at relatively low elevations and the southern and western exposures and ridge tops at the middle elevations. The natural forest succession in the absence of fire, from pine to Douglas-fir and true-firs, should be prevented or retarded.

The harvesting method should be patch clearcutting, in patches large enough to discourage rapid takeovers of the site by Douglas-fir regeneration. Planting pine when necessary in a series of patch clearcuts in the forest would help increase losses among dispersing budworm in the first and second instars.

These suggestions, in general, are similar to recommendations made for other forest types (see Morris 1955). A series of detailed and simultaneous population studies are needed in areas where climate and vegetation differ. With such data, the vulnerability of various forest types from site to site and the possibilities for controlling budworm populations through stand manipulation could be determined. Once the budworm and host subsystems and their interactions are accurately modeled, then, with the proper economic data, various forest management operations can be planned for maximum production of various forest resources with minimum budworm damage.

## SUMMARY

Williams, Carroll B. Jr., Patrick J. Shea, and Gerald S. Walton
1971. **Population density of western spruce budworm as related to stand characteristics on the Bitterroot National Forest.** Berkeley, Calif., Pacific SW. Forest & Range Exp. Sta. 8 p. (USDA Forest Serv. Res. Paper PSW-72)

*Oxford:* 453–145.7 X 18.28 *Choristoneura occidentalis:* 11 : 153 : 174.7 *Pseudotsuga menziesii* [–521.6 + 174.7 *Picea engelmannii* + *Abies* spp.].

*Retrieval Terms: Choristoneura occidentalis:* population dynamics; site factors; basal area; *Pseudotsuga menziesii; Picea engelmannii; Abies* spp.; mortality; Bitterroot N.F.

The western spruce budworm *(Choristoneura occidentalis* Freeman*)* is a major defoliator of forests in the Western United States. The main host trees are Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco*)*, Engelmann spruce *(Picea engelmannii* Parry*)*, and the true firs *(Abies* spp.*)*. Assumptions about the distribution of this forest pest within tree crowns are based on data for spruce budworm on balsam fir in eastern Canada. Evidence is needed to show whether these assumptions are correct, and to determine if sampling methods should be modified. Information is also needed on how closely various schemes of estimating defoliation and damage are related to budworm population levels so as to increase the usefulness of insect damage surveys.

Forest entomologists and managers are interested in possible relationships between stand factors that can be manipulated and levels of budworm populations. They might be able to reduce the frequency and severity of insect outbreaks and damage by regulating stand and tree conditions that contribute to high population levels.

This paper reports a study of the relation of budworm population density to certain stand conditions and damage indicators in four drainages on the Bitterroot National Forest, in western Montana.

Most western spruce budworm populations were sampled during the peak of the fifth instars. Pole pruners, extendable up to 30 feet, were used to cut two 15-inch twigs from each crown third of Douglas-fir, subalpine fir, and Engelmann spruce sample trees on 28 plots. The length and width of the twigs were

measured and the budworm larvae and new buds were counted. Five levels of shoot and total twig defoliation (0-9, 10-25, 26-50, 51-75, 76-100 percent) were estimated on each 15-inch twig. Ten levels of current year's and total tree defoliation (I=0-10 percent, II=10-20 percent..., X=90-100 percent) and four levels of cumulative damage were estimated for each study tree. Stand basal area was measured at each plot.

The relation between western spruce budworm population density and the variables listed above was examined by analysis of variance. Plot basal area, tree species, crown level, shoot and current year's defoliation were related to budworm density at the 0.005 percent level. Budworm population densities were greater on open-grown trees than on trees in dense stands. Population densities were higher on subalpine fir than on Douglas-fir and Engelmann spruce and were highest in the upper third of tree crowns and lowest in the lower third. The middle third of the crown contained an approximate average population density for Douglas-fir. Up to a point more budworms were found on the more heavily defoliated branches.

Western spruce budworm population densities were also related to total cumulative defoliation at the 0.005 percent level and to damage class estimates at the 0.893 percent level. Total cumulative defoliation and damage class estimates have only slight practical application to current budworm population density because they include previous as well as present damage.

We concluded that:

1. The approximate average population density in Douglas-firs can be obtained by sampling the mid-crown.

2. Shoot and current year's defoliation estimates are valuable indicators of budworm population levels as well as valid descriptions of current damage. The number of current year's defoliation classes can be condensed from 10 to 6.

3. Total cumulative defoliation and damage class estimates are also indicative of current budworm population levels. However, they are more useful in describing cumulative damage impact to the individual trees. The number of total defoliation classes can also be reduced from 10 to 6.

4. Tables collating tree defoliation and damage classification with western spruce budworm population levels should be constructed, tested, and evaluated as possible aids in damage surveys.

The results of this study and observations made in eastern Montana suggest that the vulnerability of western forests to excessive damage by the western spruce budworm can be reduced by:

1. Maintaining stands in thrifty, rapidly growing trees.

2. Reducing the true-fir complement in all budworm susceptible stands whenever feasible.

3. Harvesting mixed stands of Douglas-fir and ponderosa pine in such a way to favor pine regeneration.

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Relation of population density to certain stand conditions and damage indicators was analyzed in four drainages on the Bitterroot National Forest of Montana. Western spruce budworm *(Choristoneura occidentalis* Freeman*)* populations were strongly related to plot basal area, tree species, and tree crown levels, and also to current and past levels of tree defoliation. Relatively open stands of thrifty trees are recommended, with logging of true fir and Douglas-fir to favor nonhost trees, to reduce vulnerability to excessive budworm damage.

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Relation of population density to certain stand conditions and damage indicators was analyzed in four drainages on the Bitterroot National Forest of Montana. Western spruce budworm *(Choristoneura occidentalis* Freeman*)* populations were strongly related to plot basal area, tree species, and tree crown levels, and also to current and past levels of tree defoliation. Relatively open stands of thrifty trees are recommended, with logging of true fir and Douglas-fir to favor nonhost trees, to reduce vulnerability to excessive budworm damage.

*Oxford:* 453–145.7 X 18.28 *Choristoneura occidentalis:* 11 : 153 : 174.7 *Pseudotsuga menziesii* [–521.6 + 174.7 *Picea engelmannii + Abies* spp.].
*Retrieval Terms: Choristoneura occidentalis:* population dynamics; site factors; basal area; *Pseudotsuga menziesii; Picea engelmannii; Abies* spp.; mortality; Bitterroot N.F.

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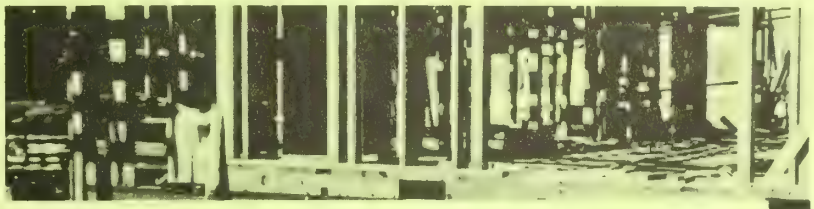
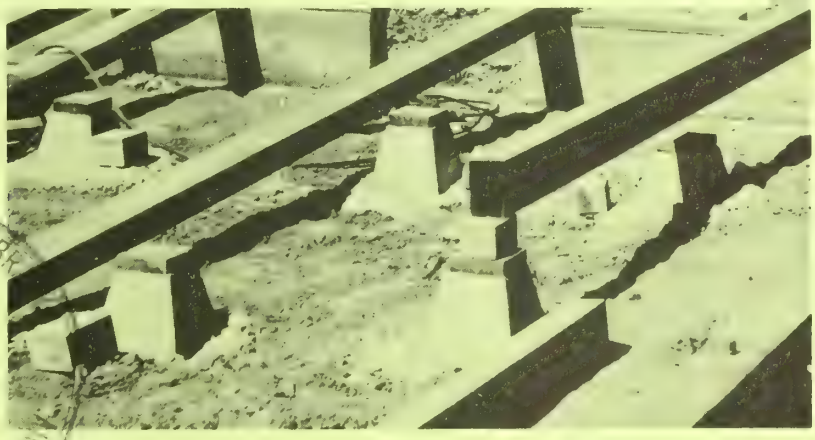


## FLOOR FOUNDATIONS: preferences of new home buyers in six Southwestern United States markets

George B. Harpole H. Edward Dickerhoof



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## The Authors

**GEORGE B. HARPOLE** has been an economist with the Station's forest products marketing research staff since 1967. He earned a B.S. degree in business administration at Montana State University (1959), and an M.S. degree in forest economics at the University of California, Berkeley (1971). He began his career with the wood products industry in California as a wholesale lumber salesman, and later worked as a sales and marketing analyst for the wood products division of Potlatch Forests, Inc., San Francisco, Calif. **H. EDWARD DICKERHOOF** is an economist in forest products marketing studies, Southeastern Forest Experiment Station, and stationed at the Forestry Science Laboratory, Athens, Ga. He joined the Forest Service in 1965, after earning degrees in business administration at Kent State University (B.S., 1962) and the University of Tennessee (M.S., 1965).

The largest new home market in the United States is in the Southwest. In California alone nearly twice as many permits are issued annually for single-family homes as in Texas, which ranks second, and in Florida, which ranks third (U.S. Bureau Census 1968).

The volumes and types of wood products used in single-family home construction are influenced by the structural designs used. Among the important design components which make up the home is the floor foundation. The amount of lumber and plywood used in a home may vary by about 20 percent, depending on whether a wood or concrete floor is used (Zaremba 1959).

To provide information that will help improve the quality of wood floor construction, the Forest Service has been studying the types of floor foundation used in single-family homes. This research has concentrated on the problems associated with both wood and concrete floors used primarily in warm climate areas of the United States, from Florida to California. The preferences and attitudes of new home buyers and of builders and architects in selected markets were surveyed.

This paper reports one phase of the study—the preferences and opinions among new home buyers in six markets in the Southwestern United States. We asked buyers to cite advantages and disadvantages of the concrete slab and the wood crawl-space floor construction. We asked them which type of floor foundation they preferred, and compared their preferences with the type in the homes they bought. And we asked for their opinions about a new design that combines a low-profile wood floor with an underfloor plenum.

To estimate annual average number of new home buyers in each of the six markets, we collected data on single-family housing permits for the years 1963 through 1967.[1] On the basis of the estimates, we selected sample populations from county records that identified the original buyers of homes built since 1963.

The six markets we studied were the counties in which these cities are located: California—Fresno, Los Angeles, Oakland-Martinez, Sacramento, and San Diego; in Arizona—Phoenix *(fig. 1)*. The estimated number of new home buyers ranged from 17,774 in Los Angeles County to 1,918 in Fresno County. The total sample consisted of 898 new home buyers. The sample size ranged from 163 in Fresno County to 188 in Los Angeles County. Questionnaires were mailed to the sample in each market. Responses ranged from a high of 57 percent in Maricopa County (Phoenix) to a low of 48 percent in Los Angeles County *(table 1)*.

We conducted followup telephone calls and personal interviews in each market to identify any important characteristics that might have been overlooked in the questionnaires. In evaluating the responses, we considered their aggregation from each market to be representative of the whole population. Weighted estimates for the "Southwest" were based on estimates of the annual average number of new home buyers in each market.

Besides wanting to determine preferences in the six markets, we wanted to know the type of floor foundation used in homes owned by new home buyers. More than half of the respondents reported concrete slab foundation; nearly a third reported crawl-space floor *(table 2)*.

[1] Significant changes in single-family housing activity have occurred in the Phoenix and Los Angeles markets since 1967. In 1969, between 12 and 13 thousand single-family building permits were issued for each of these market areas (U.S. Bureau of the Census 1970).

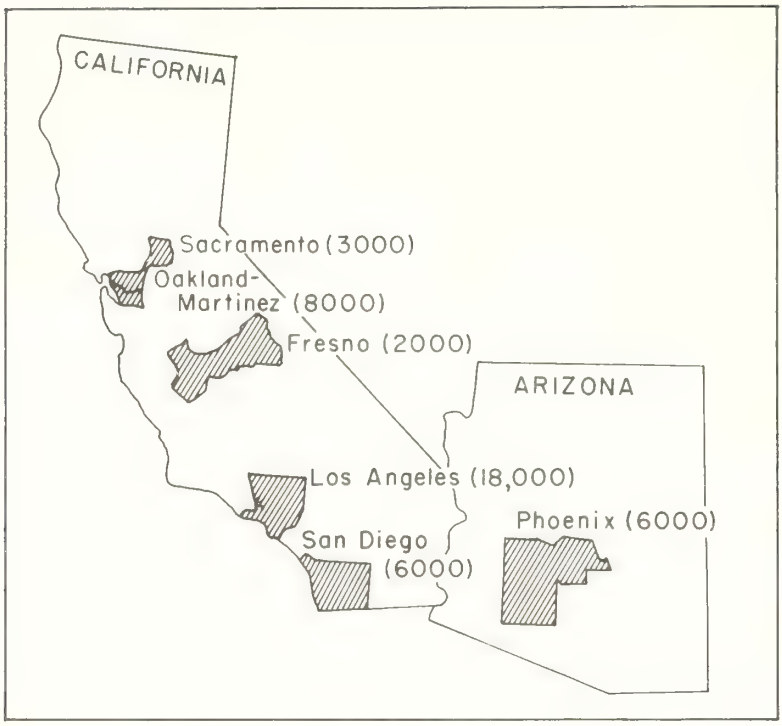


Figure 1—*The six markets surveyed for new home buyers' preferences in floor construction consisted of one or more counties corresponding to the cities shown. Numbers in parenthesis (in thousands) show the average annual number of one-unit housing permits issued from 1963 through 1967.*

Table 1—*Estimated annual average number of single-family new home buyers, sample size selected, and response for six housing markets in the southwestern United States surveyed in 1969*

| Housing markets[1] | Estimated new home buyers[2] | Sample size | Responses |
|---|---|---|---|
| | *Number* | | |
| California: | | | |
| Oakland-Martinez | 8,112 | 113 | 56 |
| Sacramento | 3,261 | 158 | 83 |
| Fresno | 1,918 | 162 | 65 |
| Los Angeles | 17,774 | 188 | 90 |
| San Diego | 5,780 | 155 | 84 |
| Arizona: | | | |
| Phoenix | 4,745 | 122 | 69 |

[1]The corresponding counties for the cities listed.

[2]Based on annual average number of single-family housing permits recorded in 1963 through 1967 (U.S. Bureau of Census 1966a, 1966b, 1967, 1968).

Table 2–*Type of floor foundations used in homes owned by new home buyers surveyed in 1969 in six markets in the southwestern United States*

| Foundations | Markets[1] | | | | | | |
|---|---|---|---|---|---|---|---|
| | Oakland-Martinez (56) | Sacramento (83) | Fresno (65) | Los Angeles (90) | San Diego (84) | Phoenix (69) | Southwest[2] |
| | *Percent* | | | | | | |
| Concrete Slab | 9 | 15 | 26 | 68 | 94 | 99 | 58 |
| Crawl-space | 71 | 55 | 66 | 19 | 2 | 0 | 30 |
| Split Level | 16 | 28 | 8 | 12 | 4 | 0 | 11 |
| No response | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| All other | 4 | 1 | 0 | 1 | 0 | 1 | 1 |
| Total | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

[1]Number of respondents shown in parentheses.

[2]Weighted on the basis of estimated annual average number of new home buyers in each market.

## COMPARISON OF FLOOR FOUNDATIONS

Each new home buyer was asked to indicate the three most important advantages and disadvantages he or she associated with using concrete slab *(fig. 2)* and wood crawl-space floor *(fig. 3)* foundation. Regardless of the type of floor construction used in their homes new home buyers shared certain attitudes about concrete slab and crawl-space floors. A high percentage of new home buyers in all six markets thought that good access to piping was an advantage of crawl-space design *(table 3 in Appendix)*. Underfoot comfort, warm floors, and the attractive appearance of hardwood floors were other advantages that

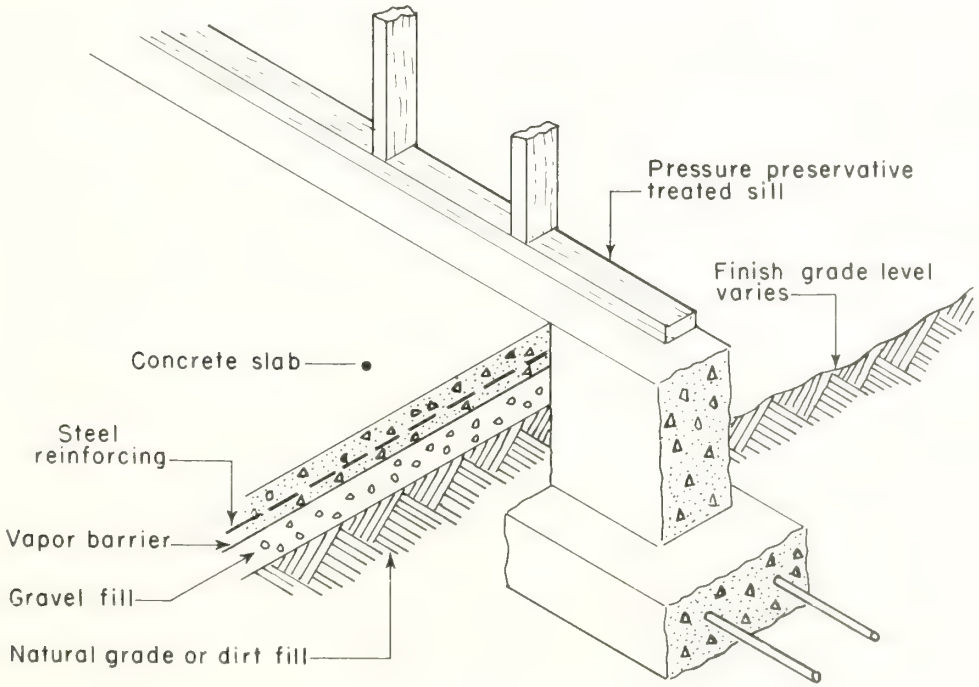


Figure 2–*The concrete slab floor is often used in homes in the Southwestern United States.*

new home buyers often associated with crawl-space construction *(table 4 in Appendix).*

In citing the disadvantages of using crawl-space construction new home buyers were apprehensive about the threat of termites and protection from other insects *(table 4 in Appendix).* The steps that are usually required from outdoor grade levels to the inside floor level of crawl-space construction were also frequently cited as a disadvantage of using crawl-space construction. Furthermore, many new home owners reported that they thought wood lacked "permanence."

Low cost was frequently cited as an important advantage of using concrete slab floor construction *(table 5 in Appendix).* Opinions were surprisingly consistent among respondents in six different markets. The highest variation in response was whether or not low-profile appearance and indoor-outdoor convenience were advantages. A high percentage of new home buyers in the Phoenix and San Diego markets cited these two characteristics as important advantages. But much less importance was placed on them by new home buyers in the Fresno, Los Angeles, Sacramento, and Oakland-Martinez markets.

Attitudes also varied between markets as to whether cold floors were a disadvantage of having concrete slabs during winter. New home owners in the warmer climates of the Fresno, Phoenix, and San Diego markets did not cite cold floors as a disadvantage as often as those in other areas with typically cooler climates *(table 6 in Appendix).* Many new home buyers indicated that other disadvantages of having concrete-slab construction were because of poor access to piping, and because concrete floors were more tiring to walk on.

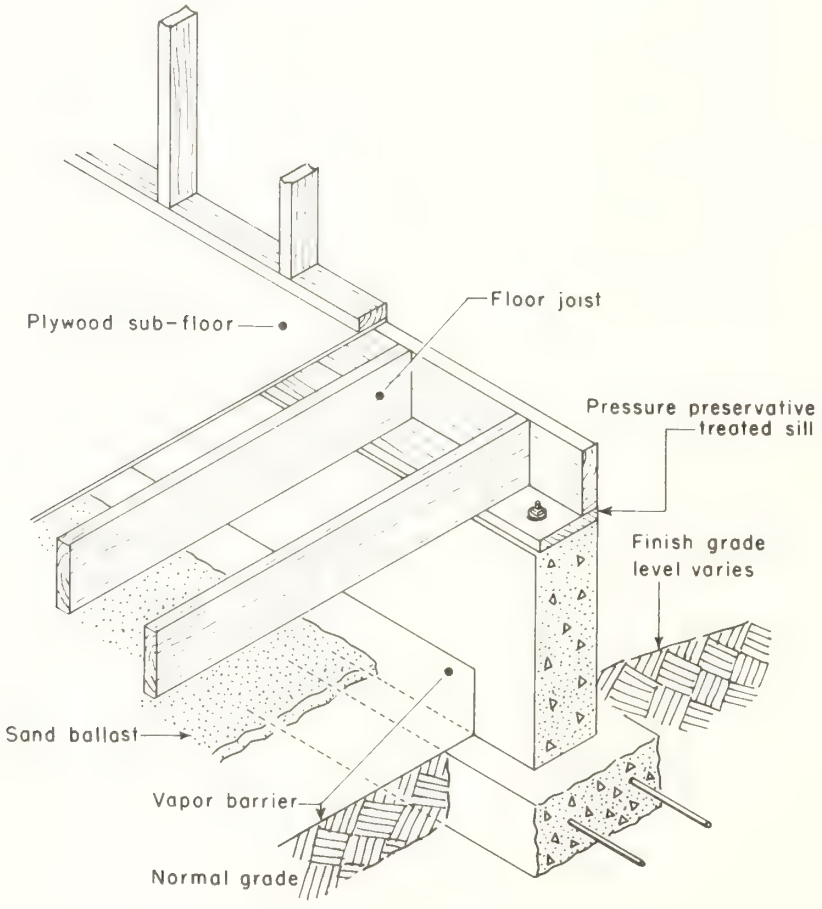


Figure 3—*The crawl-space floor is the most common floor design used in the Southwest, where terrain and soil conditions present technical problems.*

## PREFERENCES AMONG NEW HOME BUYERS

New home buyers were asked which type of floor-foundation construction they would prefer in their home; i.e., concrete slab or wood crawl-space. Responses varied to extremes between different markets. But nearly 60 percent of the new home buyers in six markets replied that they preferred wood crawl-space construction. The percent, by market, was:

| | |
|---|---|
| Oakland-Martinez | 88 |
| Sacramento | 82 |
| Fresno | 74 |
| Los Angeles | 62 |
| San Diego | 33 |
| Phoenix | 19 |

Comparisons of new home buyers' preferences with the type of floors in the homes they bought *(table 2)* point up conspicuous differences. Many new home buyers preferred wood crawl-space floors, but purchased homes with concrete slab foundation. For example, in the Los Angeles market, 62 percent of the new home buyers said they preferred a crawl-space floor, but only 19 percent had purchased homes with such construction.

On the basis of preferences either for crawl-space or for concrete slab respondents were asked to cite the three most important factors that influenced their choice. Variations between markets in climate, topography, customs, and other non-structural aspects appeared to influence the importance new home buyers placed upon different structural factors. Factors that were thought to be important in influencing a choice in preference for concrete slab construction were, for example, better protection from termites, ants, and other insects, predominant use in area, and comfortableness for the local climate *(table 7 in Appendix)*.

New home buyers who preferred wood crawl-space construction frequently indicated that a prior knowledge of this type of floor and comfortableness for the local climates were factors that influenced their final choice. Also, new home buyers reported other important influences, such as the predominant use of crawl-space construction in their local area, and the impression that a home with this type of floor would be easier to sell *(table 8 in Appendix)*. Thus, the new home buyer's attitude that his home is an investment influences his preference for type of floor construction.

## ATTITUDES TOWARD A NEW DESIGN

A new design that combines a low-profile wood floor with underfloor plenum appears to be a good alternative to concrete slab and crawl-space floor-foundations *(fig. 4)*. This type of construction includes most of the characteristics cited as important advantages of both crawl-space and concrete slab floor-foundations; that is, warm floors, adaptability to sloping sites, ability to achieve a close indoor-outdoor relationship, and low ground-hugging appearance *(fig. 5)*.

The underfloor area is used as a plenum to distribute conditioned air to each room in a house—eliminating the need for ductwork. The height of the plenum (height of the floor framing above the ground vapor barrier) can be varied to meet design preferences or building code requirements. Floor framing does not have to differ from that normally used for wood crawl-space construction; although, some experimentation has been done with floor framing and prefinished floor panels over a plenum only 4 inches deep (Stout 1960).

In Fresno, we found that underfloor plenums had been used in about 1,300 homes. Home owners who were contacted indicated that they thought the plenum was especially superior in terms of underfoot comfort. Because conditioned air is in continuous contact with the underside of the floor, the floor itself becomes an agent of heat transfer—creating warm or cool floors with the underfoot resiliency typical of crawl-space floor construction. One problem encountered in the Fresno market has been with sites where hard pan soil can create water drainage problems under and around some houses. Inadequate drainage can cause accumulations of water in the plenum area. Poor drainage can also lead to the flooding of crawl-space areas as well as concrete-slab construction. Regardless of the type of floor construction used, housing sites need to be carefully selected.

Plenum floor construction would be a first choice of many new home buyers. The advantages that they anticipated would be in this design were provision for more efficient heating and cooling, attractive hardwood floors, no ductwork, and good access to piping

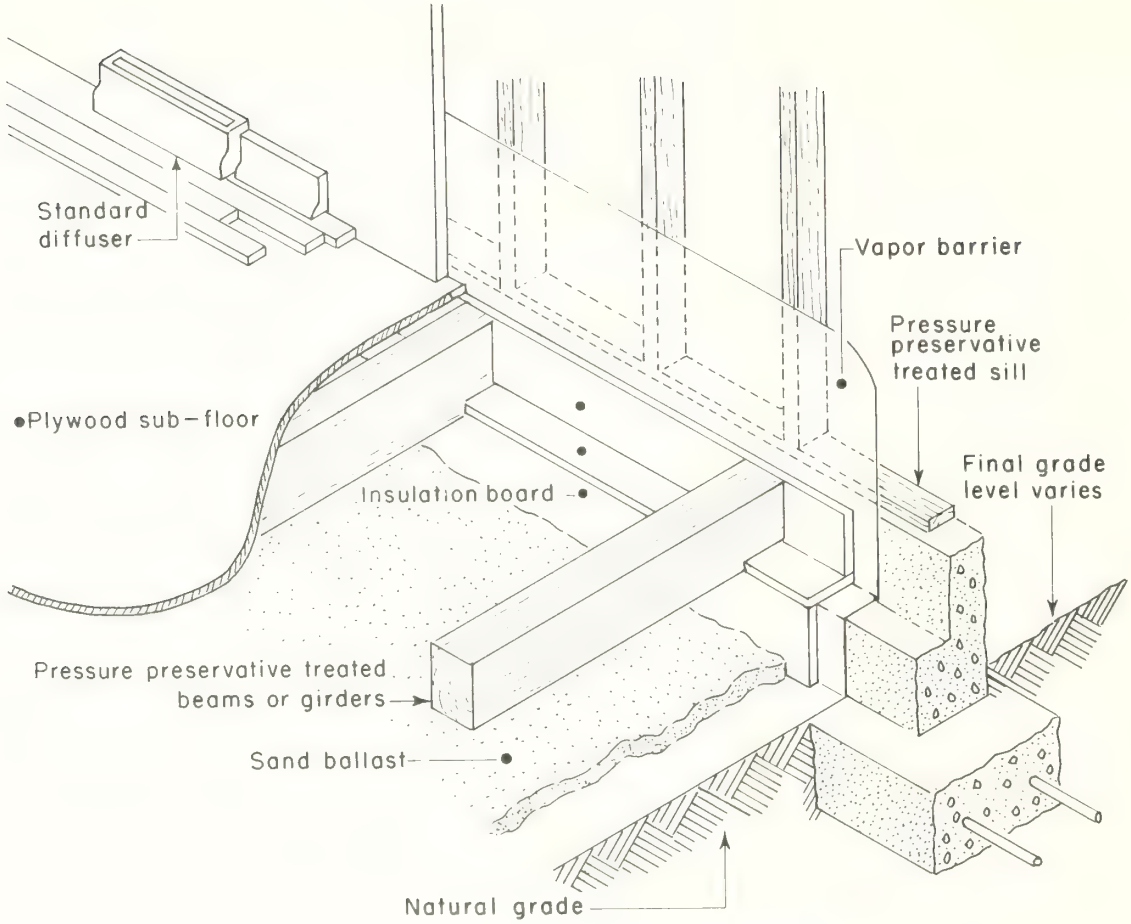


Figure 4—*A wood floor construction has been designed for use in combination with an underfloor plenum.*

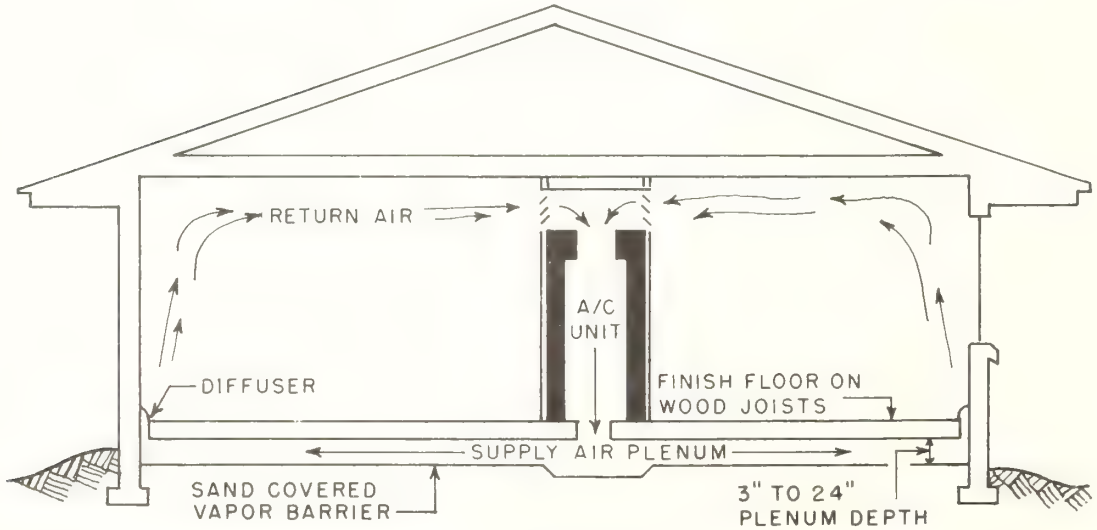


Figure 5—*The low profile plenum floor foundation design illustrates a new concept for cool and warm air distribution. The underfloor plenum provides a supply of air. Underfloor ductwork is not necessary.*

*(table 9 in Appendix).* In each of the six markets studied more than 60 percent of the respondents said they would consider buying a house with an underfloor plenum construction *even if it cost more than a house with concrete slab floor construction.* A Forest Service study on costs of plenum, slab, and crawl-space floor construction in these and other areas estimated that the cost of plenum floor construction would be competitive with that of slab construction (Dickerhoof and Lawrence 1971). A major reason was the savings in ductwork. A typical cost estimate for the installation of ductwork in a 1,680-square-foot house in the Southwest was $425 in 1969.

Some respondents in each market said they would not consider buying a house with a plenum underfloor. The highest negative response—19 percent—was in the Phoenix market. Twenty-two percent of the respondents there thought insects—especially termites—would be a problem *(table 10 in Appendix).* (Termites can, of course, become a problem with any construction if proper chemical treatment is not used.) Some responses suggested apprehension about the possibility of flooding in the plenum area, and the efficiency of heating and cooling with plenum. Both problems are potential to either wood crawl-space or concrete slab construction.

All testing and uses of the plenum design have shown that it is a potentially economical and desirable alternative to other types of floor foundation.

In 1966, the University of Florida in cooperation with the Forest Service began a study of plenum floor construction. A specially instrumented house was designed and built to test the use of a shallow plenum (about 6 inches between the floor joists and ground level) for both heating and cooling with a wood floor and floor frame *(fig. 5)* (Caldwell and Dickerhoof 1969). The moisture content in the wood floor framing maintained a seasonal range between 6 and 13 percent—a desirable range from a technical standpoint (Fasick and Dickerhoof 1970; Miller and Wagner 1969). These and other tests suggest that the plenum design can maintain a desirable environment—even in hot, cold, and humid climates (Talbot 1963; Stout 1960).

## SUMMARY


Harpole, George B., and H. Edward Dickerhoof

1971. **Floor foundations: preferences of new home buyers in six Southwestern United States markets.** Berkeley, Calif., Pacific SW. Forest & Range Exp. Sta. 12 p., illus. (USDA Forest Serv. Res. Paper PSW-73)

*Oxford:* 833.11–(079.5):(79).

*Retrieval Terms:* floor foundations; buyer preference; concrete slabs; wood frame with crawl-space; wood floor (low-profile); Arizona; California.

The preferences and opinions of new home buyers among three types of floor foundations were studied in six markets in the Southwestern United States. The three types were: (a) concrete slab, (b) wood crawl-space, and (c) a new design that combines a low profile wood floor with underfloor plenum. Questionnaires were mailed to a selected sample totaling 898 new home buyers in counties in which these cities are located: in California—Fresno, Los Angeles, Oakland-Martinez, Sacramento, and San Diego; in Arizona—Phoenix. They were followed up by telephone calls and personal interviews.

Preferences for type of floor foundation varied between different markets. In the rapidly growing Phoenix market, 80 percent of the new home buyers who responded indicated a preference for concrete slab. Martinez market preferred crawl-space construction. Many of these respondents, however, were found to have purchased homes with floor foundations that were not of their preference. For example, in the Los Angeles market, 62 percent of the new home buyers said they preferred crawl-space, but only 19 percent had purchased homes with this type of floor construction.

With both plenum and crawl-space construction, many new home buyers were concerned about the threat of termites. Some of these people may have experienced termite damage in previous homes. Others are apparently not aware that readily available chemical treatments can prevent termite attack to

wood floor and foundation construction.

More than 60 percent of the respondents in each of the six markets indicated that they would consider buying a new home with wood floor and underfloor plenum—even if this would cost more than concrete-slab construction. Cost estimates of plenum floor construction in these six markets have in fact, suggested that it would not cost more than concrete-slab construction.

Research in and actual use of underfloor plenum construction demonstrate that it does, in fact, offer several advantages common to both concrete-slab and wood crawl-space construction while minimizing disadvantages. In this study, new home buyers especially liked the potential of an improved air distribution system in combination with a wood floor. The availability of hardwood floors was also often cited as an important advantage. Thus, an opportunity exists for wood products manufacturers, trade associations, and others to assist and advise local builders and architects in promoting the construction of homes with underfloor plenums.

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## APPENDIX: *Survey Results*

A sample of new home buyers in each six markets surveyed in the Southwestern United States were asked about the. . .

- Advantages and disadvantages in using wood crawl-space floor foundation *(tables 3,4).*
- Advantages and disadvantages in using concrete slab floor foundation *(tables 5,6).*
- Factors that influenced the choice in preferences for concrete slab foundation or for wood crawl-space foundation *(tables 7,8).*
- Advantages or disadvantages anticipated by respondents of living in a home with low-profile wood floor with underfloor plenum *(tables 9,10).*

Each person queried was asked to cite as many advantages, disadvantages, or factors as he or she wanted. The tables below list only the answers most often given.

Table 3–*Advantages cited most often for using wood crawl-space floor construction*

| Advantages cited | Market[1] | | | | | | |
|---|---|---|---|---|---|---|---|
| | Oakland-Martinez (56) | Sacramento (83) | Fresno (65) | Los Angeles (90) | San Diego (84) | Phoenix (69) | Southwest[2] – |
| | *Percent* | | | | | | |
| Good access to pipes | 80 | 70 | 85 | 89 | 92 | 71 | 84 |
| Less tiring to walk on | 73 | 58 | 63 | 63 | 58 | 59 | 63 |
| Warmer than concrete floors in winter | 64 | 54 | 58 | 58 | 51 | 42 | 56 |
| Attractive appearance of hardwood floors | 39 | 43 | 29 | 43 | 55 | 51 | 44 |

[1]Number of respondents shown in parentheses.

[2]Weighted on the basis of estimated annual average number of new home buyers in each market.

Table 4–*Disadvantages most often cited for using wood crawl-space floor construction*

| Disadvantages cited | Market[1] | | | | | | |
|---|---|---|---|---|---|---|---|
| | Oakland-Martinez (56) | Sacramento (83) | Fresno (65) | Los Angeles (90) | San Diego (84) | Phoenix (69) | Southwest[2] – |
| | *Percent* | | | | | | |
| Less protection from termites | 46 | 53 | 54 | 69 | 64 | 65 | 61 |
| Steps up from ground are required | 43 | 30 | 35 | 36 | 68 | 54 | 44 |
| Less protection from ants, roaches and other insects | 38 | 39 | 43 | 48 | 42 | 39 | 43 |
| Wood lacks permanence | 25 | 33 | 28 | 34 | 40 | 41 | 34 |

[1]Number of respondents shown in parentheses.

[2]Weighted on the basis of estimated annual average number of new home buyers in each market.

Table 5—*Advantages most often cited for using concrete-slab construction*

| Advantages cited | Market[1] | | | | | | |
|---|---|---|---|---|---|---|---|
| | Oakland-Martinez (56) | Sacramento (83) | Fresno (65) | Los Angeles (90) | San Diego (84) | Phoenix (69) | Southwest[2] – |
| | *Percent* | | | | | | |
| Low cost | 75 | 77 | 62 | 64 | 67 | 75 | 69 |
| Floors cooler than crawl-space | 57 | 49 | 48 | 62 | 42 | 49 | 55 |
| Indoor-outdoor convenience | 48 | 29 | 40 | 42 | 65 | 68 | 49 |
| Low profile appearance | 27 | 29 | 35 | 41 | 46 | 45 | 38 |

[1]Number of respondents shown in parentheses.
[2]Weighted on the basis of estimated annual average number of new home buyers in each market.

Table 6—*Disadvantages most often cited for using concrete-slab construction*

| Disadvantages cited | Market[1] | | | | | | |
|---|---|---|---|---|---|---|---|
| | Oakland-Martinez (56) | Sacramento (83) | Fresno (65) | Los Angeles (90) | San Diego (84) | Phoenix (69) | Southwest[2] – |
| | *Percent* | | | | | | |
| Poor access to piping | 61 | 57 | 68 | 68 | 86 | 68 | 68 |
| Concrete floors are more tiring to walk on | 64 | 59 | 62 | 61 | 57 | 58 | 61 |
| Floors are too cold in winter | 55 | 52 | 38 | 43 | 31 | 32 | 43 |
| Chance of injury in fall | 20 | 25 | 22 | 24 | 23 | 17 | 22 |

[1]Number of respondents shown in parentheses.
[2]Weighted on the basis of estimated annual average number of new home buyers in each market.

Table 7—*Factors cited most often that influenced a choice in preferences for concrete-slab construction*

| Factors cited | Market[1] | | | | | | |
|---|---|---|---|---|---|---|---|
| | Oakland-Martinez (6) | Sacramento (12) | Fresno (16) | Los Angeles (32) | San Diego (56) | Phoenix (55) | Southwest[2] |
| | *Percent* | | | | | | |
| Better protection from termites | 33 | 33 | 50 | 69 | 68 | 67 | 65 |
| Widely used in neighborhood | 17 | 33 | 31 | 47 | 59 | 73 | 54 |
| Better protection from ants, roaches & other insects | 17 | 17 | 38 | 44 | 39 | 29 | 37 |
| More comfortable for local climate | 33 | 8 | 19 | 19 | 20 | 35 | 24 |

[1]Number of respondents who preferred concrete-slab construction shown in parentheses.
[2]Weighted on the basis of estimated annual average number of new home buyers in each market.

Table 8—*Factors cited most often that influenced a choice in preference for wood crawl-space construction*

| Factors cited | Market[1] | | | | | | |
|---|---|---|---|---|---|---|---|
| | Oakland-Martinez (49) | Sacramento (68) | Fresno (48) | Los Angeles (56) | San Diego (28) | Phoenix (13) | Southwest[2] |
| | *Percent* | | | | | | |
| Makes home easier to sell | 65 | 69 | 48 | 54 | 36 | 38 | 56 |
| Prior knowledge of this type of floor system | 59 | 51 | 57 | 56 | 54 | 54 | 56 |
| More comfortable for local climate | 51 | 24 | 38 | 20 | 11 | 15 | 29 |
| Widely used in area | 43 | 43 | 35 | 41 | 32 | 46 | 41 |

[1]Number of respondents who preferred wood crawl-space construction shown in parentheses.
[2]Weighted on the basis of estimated annual average number of new home buyers in each market.

Table 9–*Anticipated advantages of living in a home with a low-profile plenum floor and foundation cited by new home buyers*

| Advantages cited | Market[1] | | | | | | |
|---|---|---|---|---|---|---|---|
| | Oakland-Martinez (56) | Sacramento (83) | Fresno (65) | Los Angeles (90) | San Diego (84) | Phoenix (69) | Southwest[2] – |
| | *Percent* | | | | | | |
| More efficient heating and cooling, better air distribution | 20 | 40 | 28 | 43 | 45 | 51 | 38 |
| Hardwood floors | 5 | 7 | 2 | 14 | 23 | 25 | 14 |
| No ducts | 5 | 7 | 12 | 9 | 2 | 10 | 7 |
| Easy access to pipes and wiring | 2 | 1 | 3 | 2 | 8 | 10 | 4 |

[1]Number of responents shown in parentheses.
[2]Weighted on the basis of estimated annual average number of new home buyers in each market.

Table 10–*Anticipated disadvantages of living in a home with a low-profile plenum floor and foundation as cited by new home buyers*

| Disadvantages cited | Market[1] | | | | | | |
|---|---|---|---|---|---|---|---|
| | Oakland-Martinez (56) | Sacramento (83) | Fresno (65) | Los Angeles (90) | San Diego (84) | Phoenix (69) | Southwest[2] – |
| | *Percent* | | | | | | |
| Poor access | 16 | 17 | 9 | 17 | 11 | 1 | 13 |
| Insect threat especially termites | 7 | 6 | 5 | 14 | 5 | 22 | 11 |
| Inefficient heating and cooling | 4 | 13 | 3 | 10 | 14 | 12 | 10 |
| Water problems | 7 | 7 | 11 | 7 | 4 | 6 | 7 |

[1]Number of respondents shown in parentheses.
[2]Weighted on the basis of estimated annual average number of new home buyers in each market.



GPO 981-315

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Harpole, George B., and H. Edward Dickerhoof

1971. **Floor foundations: preferences of new home buyers in six Southwestern United States markets.** Berkeley, Calif., Pacific SW. Forest & Range Exp. Sta. 12 p., illus. (USDA Forest Serv. Res. Paper PSW-73)

Mail questionnaires and follow-up interviews were used to determine preferences among three types of floor foundations: concrete slab, wood crawl-space, and a new design that combines a low-profile wood floor with underfloor plenum. More respondents from northern markets preferred the crawl-space floor than from the southern markets. Factors most often cited as influencing preference were protection from termites, expected ease of reselling a house, and previous knowledge of or experience with a type of floor construction.

*Oxford:* 833.11–(079.5):(79).
*Retrieval Terms:* floor foundations; buyer preference; concrete slabs; wood frame with crawl space; wood floor (low-profile); Arizona; California.

Harpole, George B., and H. Edward Dickerhoof

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PSW-74

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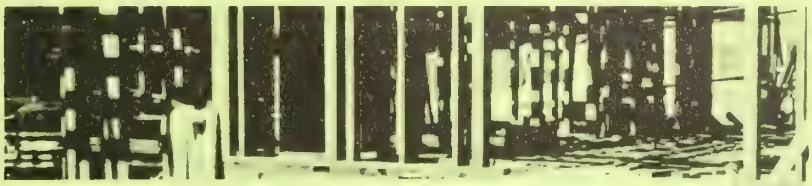

## FLOOR FOUNDATIONS: preferences of architects and builders in six Southwestern United States markets

George B. Harpole H. Edward Dickerhoof

USDA FOREST SERVICE RESEARCH PAPER PSW- 74 /1971

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**GEORGE B. HARPOLE** has been an economist with the Station's forest products marketing research staff since 1967. He earned a B.S. degree in business administration at Montana State University (1959), and an M.S. degree in forest economics at the University of California, Berkeley (1971). He began his career with the wood products industry in California as a wholesale lumber salesman, and later worked as a sales and marketing analyst for the wood products division of Potlatch Forests, Inc., San Francisco, Calif. **H. EDWARD DICKERHOOF** is an economist in forest products marketing studies, Southeastern Forest Experiment Station, and stationed at the Forestry Science Laboratory, Athens, Ga. He joined the Forest Service in 1965, after earning degrees in business administration at Kent State University (B.S., 1962) and the University of Tennessee (M.S., 1965).

In a typical single-family home in the United States, the volume of wood products used in its construction can vary by as much as 3,000 feet per house—depending on the type of floor foundation selected. Because of this importance of floor design, the Forest Service has been evaluating the design trends and market preferences that affect the types of floor foundations. In an earlier report (Harpole and Dickerhoof 1971), we summarized results of one phase of the study—the preferences and attitudes of new home buyers in six Southwestern United States markets among three types of floor foundations: (a) concrete slab, (b) wood crawl-space, and (c) a new design that combines a low-profile wood floor with underfloor plenum.

This paper reports another phase of the study, in the same six markets. Builders and architects were asked about their preferences between concrete slab and wood crawl-space construction, and for their opinions about the new plenum design.

The six markets selected were considered representative of the many housing markets in the Southwest. They were the counties in which these cities are located: in California—Fresno, Los Angeles, Oakland-Martinez, Sacramento, and San Diego; in Arizona—Phoenix *(fig. 1)*.

The number of architects was estimated on the basis of telephone directory listings found in each market *(table 1)*. A representative sample was then drawn from this population. The number of builders

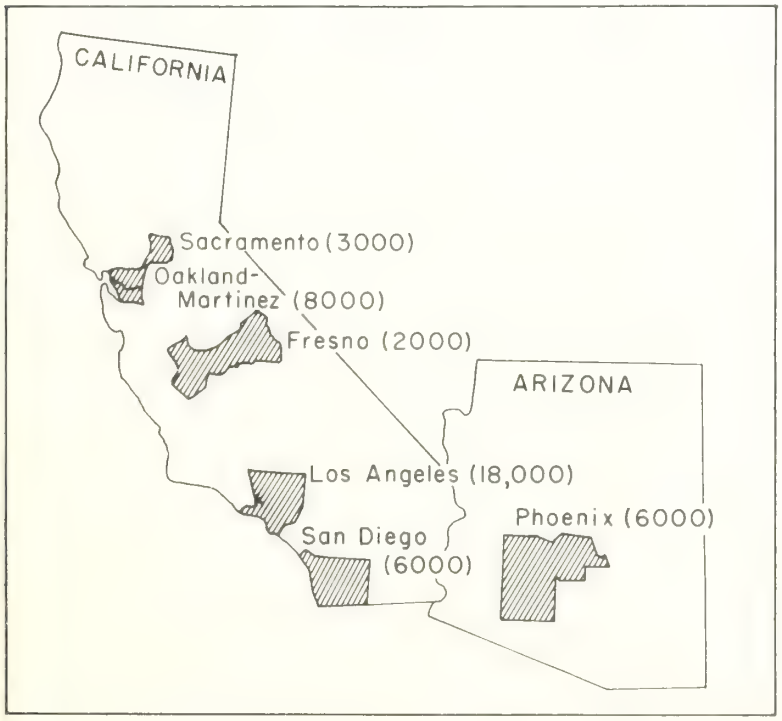



Figure 1—*The six markets surveyed for preferences of architects and builders in floor construction consisted of one or more counties corresponding to the cities shown. Numbers in parenthesis (in thousands) show the average annual number of one-unit housing permits issued from 1963 through 1967.*

Table 1—*Population estimates, sample size, and sample responses of architects and builders surveyed in six Southwestern housing markets, 1969*

| Sample characteristics | Oak-Martinez | | Sacramento | | Fresno | | Los Angeles | | San Diego | | Phoenix | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr |
| Estimate of total population . . No. | 397 | 557 | 65 | 266 | 30 | 77 | 358 | 1,100 | 90 | 380 | 108 | 146 |
| Sample Size . . No. | 40 | 68 | 33 | 33 | 15 | 14 | 36 | 58 | 27 | 46 | 32 | 26 |
| Total number of responses . . . No. | 27 | 44 | 29 | 25 | 13 | 10 | 24 | 42 | 21 | 35 | 23 | 11 |
| Responses of sample . . . . . pct. | 67 | 65 | 88 | 76 | 87 | 71 | 67 | 72 | 74 | 76 | 72 | 62 |
| Respondents designing one-story SFRH[1] . . . . . No. | 9 | 24 | 15 | 16 | 6 | 7 | 10 | 16 | 11 | 23 | 13 | 15 |
| Respondents designing one-story SFRH[1] . . . . pct. | 23 | 35 | 45 | 48 | 40 | 50 | 28 | 28 | 41 | 50 | 41 | 58 |
| Estimated populations designing and/or building one-story SFRH . . . . . No. | 132 | 303 | 34 | 171 | 14 | 54 | 149 | 42 | 47 | 249 | 61 | 140 |

[1]SFRH = Single-family residential homes.

was estimated on the basis of the membership listings of the Home Builders' Association in each market. Members of these associations were estimated to include about 35 percent of all new home builders in each market. We mailed nearly identical questionnaires both architects and builders. Responses from architects ranged from a low of 67 percent in the Oakland-Martinez and Los Angeles markets to a high of 88 percent in Sacramento. Builder responses ranged from a low of 62 percent in Phoenix to a high of 76 percent in the Sacramento and San Diego markets.

We conducted follow-up telephone calls and personal interviews with both respondents and nonrespondents to identify any important market characteristics that might have otherwise been overlooked in the mail questionnaires. Architects and builders who did only commercial work, or did not design or build one-story single-family homes were asked not to complete their questionnaires.

In the evaluation of questionnaires, the responses from each market were considered to be representative of the local distribution of preferences and opinions. Estimates of the prevalence of preferences and opinions in the Southwest were based upon the weighting of the different market responses by the estimated local populations of architects who designed and builders who built one-story single-family homes.

## COMPARISONS OF FLOOR FOUNDATIONS

Architects and builders were asked to indicate the three most important advantages and three most important disadvantages that they associated with using concrete slab and wood crawl-space construction *(figs. 2,3)*. Regardless of the type of floor system they preferred architects and builders generally agreed about what was important to consider when evaluating floor foundations *(tables 2, 3, 4, 5 in Appendix)*.

Builders and architects commonly agreed that wood crawl-space floors offer better access to piping and were less tiring to walk on than concrete-slab floors. But they also frequently pointed out that steps were required to reach from outdoor ground levels to typical crawl-space floor levels, and that concrete-slab foundations could be constructed with lower material and labor costs. And they noted that it is easier to achieve a low ground-hugging appearance

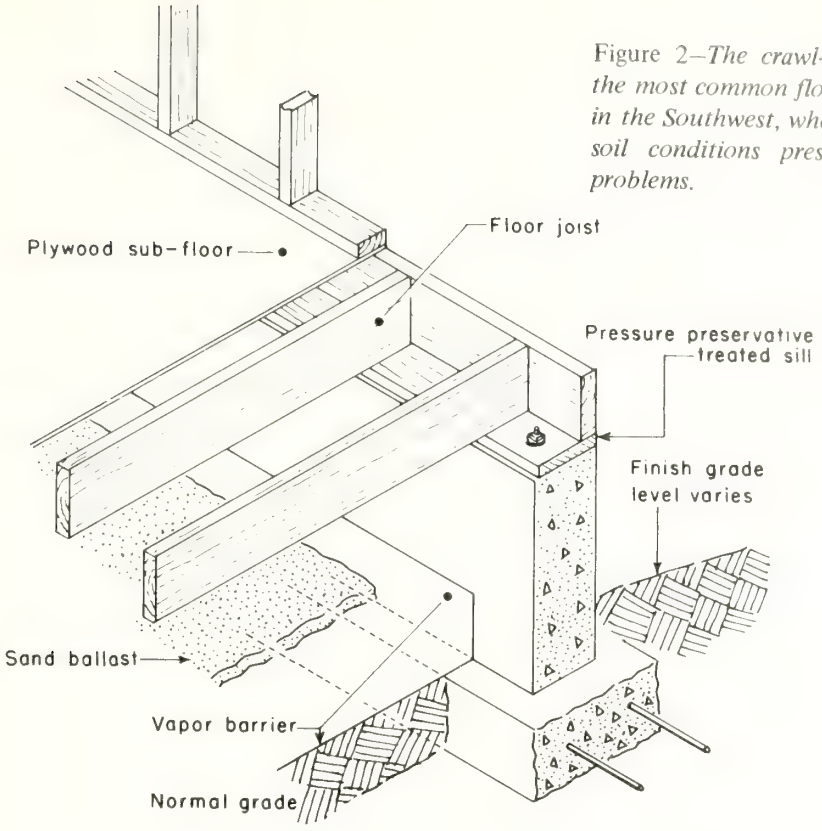



Figure 2—*The crawl-space floor is the most common floor design used in the Southwest, where terrain and soil conditions present technical problems.*

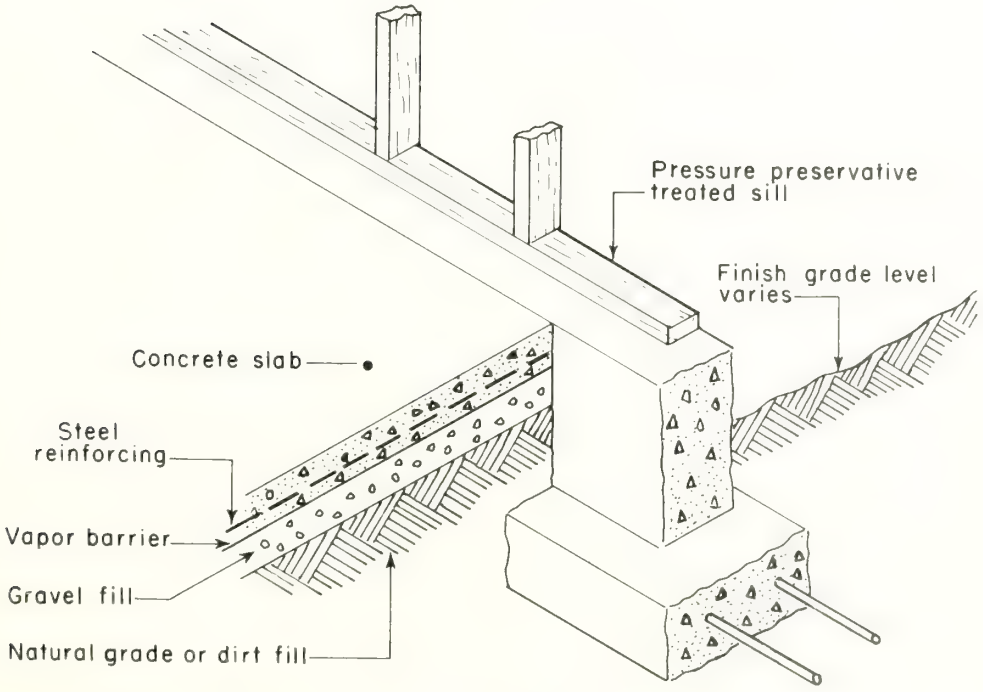



Figure 3—*The concrete slab floor is often used in homes in the Southwestern United States.*

with concrete-slab floors than with wood crawl-space floors.

Architects were more sensitive to design considerations than builders. They repeatedly cited crawl-space floors as advantageous for sloping sites—even in Phoenix, where all architects and builders preferred concrete-slab foundations. Architects indicated more frequently than builders, that they thought crawl-space floors were warmer than concrete-slab floors, that concrete-slab floors could be a potential problem because of cracks, and that concrete-slab floors afforded better indoor-outdoor convenience. Architects and builders consistently indicated the importance of the cost of materials and labor in their evaluations of both floor types.

## PREFERENCES AMONG ARCHITECTS AND BUILDERS

Architects' and builders' preferences for floor-foundation varied. Sacramento architects preferred crawl-space designs more often than the local builders *(table 6 in Appendix).* In Fresno, the situation was reversed; that is, builders preferred crawl-space designs more often than did architects. In Los Angeles, builders preferred concrete-slab floors more often than crawl-space floors. About 30 percent of the architects in that market indicated that they had no particular preference between either crawl-space or concrete-slab foundations.

In some markets, builders and architects were closely aligned in their preferences, although, preferences for either crawl-space or concrete-slab design varied from one market to another. In Phoenix, all builder and architect respondents preferred concrete-slab floors; but in the Oakland-Martinez market, both builders and architects strongly favored crawl-space designs. In comparing preferences in the Southwest among architects, builders, and new home buyers, we noted striking differences. In most of the six markets we studied, the percentage of new home buyers who preferred crawl-space construction was higher than that of either the local builders or architects (Harpole and Dickerhoof 1971). This difference was conspicuous in Phoenix, where 19 percent of the new home buyers queried preferred a crawl-space floor foundation when all of the local architects and builders preferred concrete-slab foundations.

On the basis of preferences—for either crawl-space or concrete-slab designs—respondents were asked to indicate the three most important factors that influenced their choice *(tables 7,8 in Appendix).* Variations between markets in climate, topography, customs, and other nonstructural aspects appeared to influence the importance each respondent placed upon different structural considerations. Such factors as the local building traditions, the preferences of customers, the favorability of terrain and soil conditions, and the predictability of performance were typical of those most often cited as having influenced a final choice.

## ATTITUDES TOWARD NEW DESIGN

The low-profile wood floor with underfloor plenum appears to be a good alternative to the concrete-slab and crawl-space floors *(figs. 4, 5).* An important advantage of this new type of construction is that it combines most of the characteristics cited as important either in crawl-space or in concrete-slab floors; that is, warm floors, adaptability to sloping sites, a close indoor-outdoor relationship, and low ground-hugging appearance. The underfloor area is used as a plenum to distribute conditioned air to each room in the house— eliminating the need for ductwork. The height of the plenum (height of the floor framing above the ground vapor barrier) can be varied to meet design preferences or building code requirements. Floor framing does not have to differ from that normally used for wood crawl-space construction, although some experimentation has been done with floor framing and prefinished floor panels over a plenum only 4 inches deep (Stout 1960).

In 1966, the University of Florida in cooperation with the Forest Service began a study of plenum floor construction (Caldwell and Dickerhoof 1969). This test emphasized the use of a shallow (about 6 inches between the floor joists and ground level) plenum for heating and cooling with a wood floor and floor frame *(fig. 5).* The moisture content in the wood floor framing maintained a seasonal range between 6

Figure 4—*The low-profile plenum floor uses a new method of cool and warm air distribution. The underfloor plenum provides an air supply. Underfloor ductwork is not necessary.*

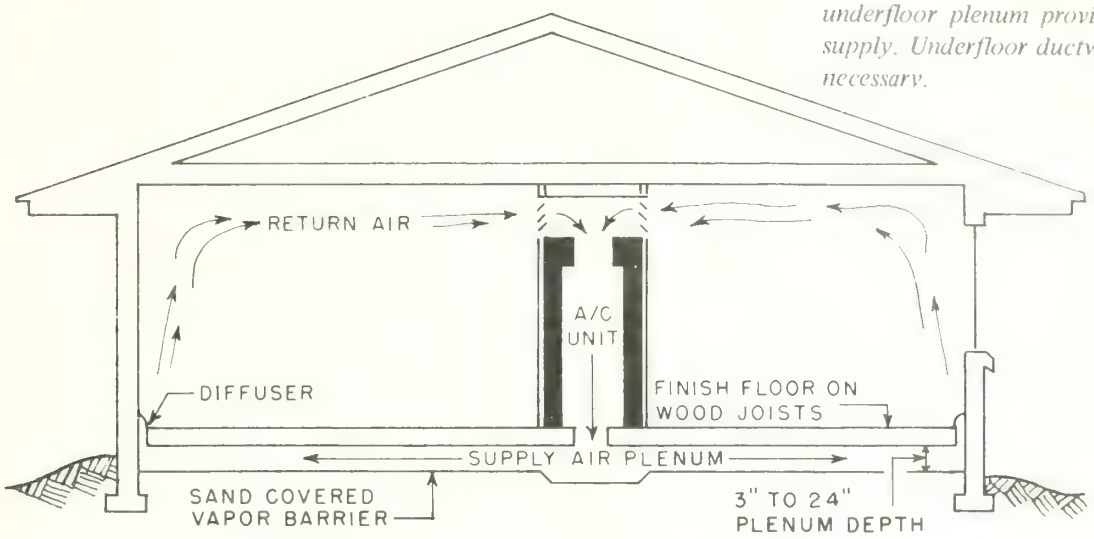
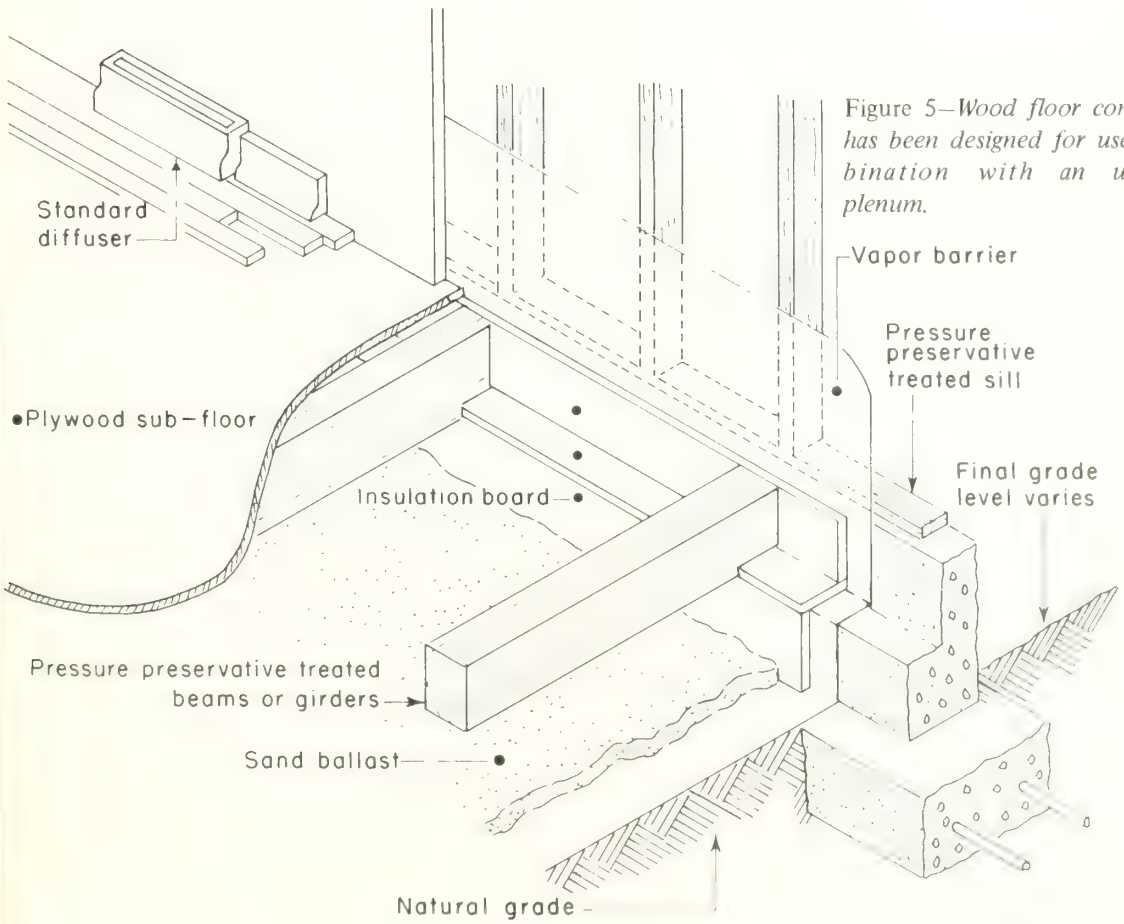



Figure 5—*Wood floor construction has been designed for use in combination with an underfloor plenum.*



and 13 percent—a desirable range (Fasick and Dickerhoof 1970; Miller and Wagner 1969). Continuous test observations suggest that the plenum design can maintain a desirable environment—even under different adverse conditions of hot, cold, and humid climates (Miller and Wagner 1969; Stout 1960; Talbot 1963).

In Fresno, we found that underfloor plenum design had been used in about 1,300 homes. Home owners who were contacted indicated that they thought this type of floor was especially superior in terms of underfoot comfort. Because conditioned air is in continuous contact with the underside of the floor, the floor itself becomes an agent of heat transfer—creating warm or cool floors with the underfoot resiliency typical of crawl-space floor construction. Some problems have been encountered in Fresno where sites with hard pan soil can create water drainage problems under and around some houses. But site evaluation is important to avoid problems that may occur—whether in crawl-space, concrete slab, or underfloor plenum design.

Most of the architects and builders we queried indicated that they were interested in the plenum floor design. Their interests were based upon their own expectations, preferences, and knowledge of their local markets. And as might be expected, some respondents in each area replied that they would not consider using the plenum even it it cost less than any of the designs they were now using. The importance attributed to different factors varied, but the most frequent expectations cited as advantages of the plenum construction were warm floors, more efficient heating and cooling, low-profile appearance, and elimination of ductwork *(table 9 in Appendix).* Architects responded more often to the design factors than builders; these factors included warm floors and low profile appearance.

The principal reservations of builders and architects toward the plenum floor had to do with heating efficiency, cooling efficiency, and cost of construction *(table 10 in Appendix).* A related Forest Service study that estimated the costs of plenum, concrete-slab and crawl-space construction in 24 cities found that plenum construction would not cost as much as crawl-space construction and in most cities not as much as slab construction (Dickerhoof and Lawrence 1971). A major reason for this economy was the savings in ductwork. A typical cost estimate for the installation of insulated ductwork in a 1,680-square-foot house in the Southwest was $425 in 1970.

In the study of new home buyers' attitudes and preferences, we found that more than 60 percent of the respondents said they would consider buying a house with an underfloor plenum even if it cost more than a house with concrete slab construction (Harpole and Dickerhoof 1971). More than 75 percent of the new home buyer respondents in Los Angeles, Oakland-Martinez, and Sacramento reported an interest in this type of floor design.

## SUMMARY


Harpole, George B., and H. Edward Dickerhoof

1971. **Floor foundations: preferences of architects and builders in six Southwestern United States markets.** Berkeley, Calif., Pacific SW. Forest & Range Exp. Sta. 11 p., illus. (USDA Forest Serv. Res. Paper PSW-74).

*Oxford:* 833.11–(079.5):(79).

*Retrieval Terms:* floor foundations; builder preference; concrete slabs; wood frame with crawl space; wood floor (low-profile); Arizona; California.

The preferences and opinions of architects and builders among three types of floor foundations were studied in six markets in the Southwestern United States. The three types were (a) concrete slab, (b) wood crawl-space, and (c) a new design that combines a low profile wood floor with underfloor plenum. Questionnaires were mailed to a selected sample totaling 428 architects and builders in counties in which these cities are located: in California—Fresno, Los Angeles, Oakland-Martinez, Sacramento, and San Diego; in Arizona—Phoenix. They were followed up by telephone calls and personal interviews.

Architects' and builders' preferences for crawl-space and concrete slab floors were found to vary among the six markets. The builders in the Fresno, Sacramento, and Oakland-Martinez markets indicated

strong preferences for crawl-space floors. Most of the architects in the Sacramento and Oakland-Martinez markets also preferred this type of design. But most of the architects in the Fresno, Los Angeles, San Diego, and Phoenix markets, and most of the builders in the Los Angeles, San Diego, and Phoenix markets preferred the concrete slab floors.

The crawl-space floor was often cited by architects and builders in all markets for a number of special advantages, such as adaptabiity to terrain, underfloor access, underfoot comfort and warmth, and attractiveness of hardwood floors when installed. Home builders and architects are aware of these advantages in crawl-space floors, but they are also aware of some disadvantages that they consider important. Crawl-space construction is commonly considered to be too costly, in most instances, to compete in cost-conscious markets. And many respondents did not like the design of crawl-space construction because of profile appearance and indoor-outdoor access. They often thought of it as more susceptible to termites and other insects.

Of the builders who preferred concrete-slab construction rather than crawl-space construction, the most frequently given reasons were that fewer "call backs" were expected, and it was the most commonly used type in the area. Another advantage often cited was the speed with which concrete construction could proceed where the terrain conditions were favorable. Still other advantages mentioned were the relative low cost of labor and materials, and the indoor-outdoor convenience.

The disadvantages of using concrete-slab floors are apparently not serious, or they are disadvantages that can be overcome. Many builders and architects indicated that a concrete-slab is more tiring to walk on. But, by using carpets and padded underlayments over slabs builders are able to reduce potential customer complaints about underfoot discomfort and cold floors while at the same time offering a touch of luxury. Builders did not mention any customer complaints about carpet installation costs or future carpet maintenance or replacement costs. Nor does poor access to piping deter most architects or builders from using concrete-slab construction.

When the advantages and disadvantages of both the wood crawl-space and concrete-slab floors are weighed, the concrete-slab design appears to hold a commanding preference in those markets that have relatively more favorable terrain for this type of floor and are least affected by cold weather.

More than 60 percent of the architects and builders queried in this study replied that they would consider using the new underfloor plenum design. As with any new development, architects and builders have to be convinced that this type of floor is practical, is cost competitive, and is acceptable to new home buyers.

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# APPENDIX: *Survey Results*

A sample of architects and builders in six markets surveyed in the Southwestern United States were asked about the. . .

- Advantages and disadvantages in using wood crawl-space floor foundation *(tables 2,3).*
- Advantages and disadvantages in using concrete-slab floor foundation *(tables 4, 5).*
- Preference between wood crawl-space floors and concrete-slab floors *(table 6).*
- What factors most often influence a preference for wood crawl-space floor or concrete-slab floor *(tables 7,8).*
- Advantages and disadvantages anticipated by respondents in using a low-profile wood floor with underfloor plenum *(tables 9, 10).*

Each person queried was asked to cite the most important advantages or disadvantages or the most important factors that affected their choice. The tables below list only the answers most often given.

Table 2—*Advantages most often cited for using wood crawl-space contruction*

| Advantages cited | Market | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oak-Martinez | | Sacramento | | Fresno | | Los Angeles | | San Diego | | Phoenix | | Southwest[1] | |
| | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr |
| | *Percent* | | | | | | | | | | | | | |
| Good for sloping site | 89 | 67 | 85 | 68 | 64 | 16 | 100 | 44 | 91 | 83 | 62 | 35 | 88 | 57 |
| Good access to piping | 78 | 62 | 74 | 73 | 86 | 84 | 90 | 69 | 83 | 61 | 39 | 35 | 77 | 64 |
| Warmer than concrete floors in winter | 22 | 42 | 47 | 25 | | 26 | 50 | 19 | 28 | 9 | 69 | 27 | 40 | 24 |
| Less tiring to walk on compared with concrete slab | 11 | 38 | 59 | 50 | 86 | 58 | 40 | 44 | 55 | 48 | 62 | 14 | 39 | 42 |
| Attractive appearance of hardwood floors | | 12 | – | 25 | | | 10 | 12 | – | 26 | 8 | 14 | 5 | 16 |
| All weather construction facilitated | 22 | 12 | 6 | 12 | 14 | 100 | 20 | 12 | – | 9 | – | 6 | 14 | 15 |

[1]Based on estimated market populations of architects and builders designing and/or building one-story single-family residential homes.

Table 3—*Disadvantages most often cited for using wood crawl-space construction*

| Disadvantages cited | Market | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oak-Martinez | | Sacramento | | Fresno | | Los Angeles | | San Diego | | Phoenix | | Southwest[1] | |
| | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr |
| | *Percent* | | | | | | | | | | | | | |
| Higher labor or material cost of both | 100 | 63 | 59 | 55 | 50 | 74 | 50 | 87 | 72 | 78 | 85 | 47 | 73 | 71 |
| Difficult to achieve low ground-hugging appearance | 56 | 46 | 59 | 73 | 50 | 26 | 100 | 63 | 55 | 56 | 39 | 27 | 69 | 54 |
| Steps up from ground required | 56 | 46 | 85 | 37 | 50 | 42 | 40 | 31 | 64 | 53 | 39 | 35 | 51 | 40 |
| Termite threat | 22 | 12 | 32 | 18 | 50 | 16 | 20 | 25 | 36 | 17 | 54 | 27 | 29 | 20 |
| Difficult to heat | 11 | | 6 | 32 | 64 | - | 40 | 25 | 19 | 26 | 8 | | 23 | 17 |
| Insect threat | - | 12 | 21 | 12 | 14 | 16 | 10 | 12 | 28 | 13 | 39 | 6 | 14 | 12 |

[1]Based on estimated market populations of architects and builders designing and/or building one-story single-family residential homes.

Table 4—*Advantages most often cited for using concrete-slab construction*

| Advantages cited | Market | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oak-Martinez | | Sacramento | | Fresno | | Los Angeles | | San Diego | | Phoenix | | Southwest[1] | |
| | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr |
| | *Percent* | | | | | | | | | | | | | |
| Low labor cost | 89 | 41 | 47 | 37 | | 58 | 30 | 50 | 36 | 53 | 85 | 61 | 57 | 49 |
| Indoor-outdoor convenience | 56 | 33 | 85 | 55 | 86 | 42 | 80 | 12 | 83 | 48 | 46 | 14 | 69 | 31 |
| Low ground-hugging appearance | 67 | 55 | 53 | 80 | | 42 | 80 | 69 | 72 | 66 | 39 | 35 | 68 | 62 |
| Low cost of concrete material | 78 | 67 | 65 | 68 | | 26 | 60 | 69 | 72 | 75 | 92 | 82 | 70 | 69 |
| Predictability of performance | | 8 | 21 | 18 | | 16 | 20 | 44 | 28 | 31 | 39 | 53 | 17 | 30 |
| Absence of squeak and other floor generated noise | | | 6 | | 57 | | 20 | | 9 | | | | 10 | |

[1]Based on estimated market populations of architects and builders designing and/or building one-story single-family residential homes.

Table 5—*Disadvantages most often cited for using concrete-slab construction*

| Disadvantages cited | Market | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oak-Martinez | | Sacramento | | Fresno | | Los Angeles | | San Diego | | Phoenix | | Southwest[1] | |
| | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr |
| | *Percent* | | | | | | | | | | | | | |
| Not good for sloping sites | 100 | 62 | 59 | 62 | 64 | 16 | 100 | 37 | 83 | 92 | 39 | 47 | 85 | 56 |
| Poor access to piping | 67 | 62 | 65 | 55 | 50 | 58 | 60 | 50 | 64 | 39 | 46 | 35 | 61 | 50 |
| Potential problem with cracks | 45 | | 32 | 32 | 36 | 16 | 40 | 56 | 28 | 34 | 62 | 47 | 43 | 34 |
| More tiring to walk on | 22 | 30 | 79 | 32 | 64 | 42 | 40 | 44 | 36 | 44 | 39 | 20 | 38 | 36 |
| Cold floors | 22 | 38 | 32 | 32 | | 42 | 50 | 25 | 36 | 17 | 31 | 27 | 35 | 28 |
| Difficult to construct in mud | | 12 | | 18 | 14 | 42 | | 12 | | 22 | | 20 | 1 | 17 |

[1]Based on estimated market populations of architects and builders designing and/or building one-story single-family residential homes.

Table 6—*Preference for wood crawl-space or concrete-slab floor construction in new homes built or designed*

| Floor construction preferred | Market | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oak-Martinez | | Sacramento | | Fresno | | Los Angeles | | San Diego | | Phoenix | | Southwest[1] | |
| | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr |
| | *Percent* | | | | | | | | | | | | | |
| Crawl-space | 77 | 88 | 79 | 55 | 14 | 84 | 30 | 19 | 19 | 26 | | | 42 | 41 |
| Concrete slab | 11 | 12 | 15 | 43 | 86 | 16 | 40 | 81 | 72 | 66 | 100 | 100 | 43 | 57 |
| No preference | 12 | – | 6 | 2 | | – | 30 | | 9 | 8 | | – | 15 | 2 |

[1]Based on estimated market populations of architects and builders designing and/or building one-story single-family residential homes.

Table 7–*Factors cited most often that influenced preference for wood crawl-space construction*

| Factors | Market | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oak-Martinez | | Sacramento | | Fresno | | Los Angeles | | San Diego | | Phoenix | | Southwest[1] | |
| | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr |
| | *Percent* | | | | | | | | | | | | | |
| Clients prefer crawl-space construction | 73 | 90 | 81 | 97 | 100 | 50 | 67 | 100 | | 65 | – | - | 69 | 87 |
| Predictability of performance | 73 | 43 | 41 | 32 | 100 | 19 | 33 | 32 | – | 35 | - | – | 55 | 37 |
| Traditional to area | 43 | 71 | 15 | 76 | - | 88 | – | - | | 17 | – | – | 26 | 57 |
| Favorable terrain and soil conditions | 28 | 38 | 15 | 21 | – | 19 | 67 | – | – | 65 | – | – | 34 | 31 |
| Familiarity with materials and construction | 15 | 43 | 15 | 12 | – | 31 | 33 | – | 44 | 35 | – | – | 21 | 30 |
| Speed of construction | 15 | 10 | – | – | – | 50 | 33 | 32 | – | – | – | - | 16 | 13 |

[1]Based on estimated market populations of architects and builders designing and/or building one-story single-family residential homes.

Table 8–*Factors cited most often that influenced preference for concrete-slab construction*

| Factors | Market | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oak-Martinez | | Sacramento | | Fresno | | Los Angeles | | San Diego | | Phoenix | | Southwest[1] | |
| | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr |
| | *Percent* | | | | | | | | | | | | | |
| Few call backs required | - | 31 | | 27 | – | 100 | 25 | 85 | – | 60 | | – | 8 | 56 |
| Favorable terrain and soil conditions | – | – | 40 | 27 | 58 | 100 | 51 | 8 | – | 33 | 69 | 40 | 44 | 22 |
| Speed of installation | 100 | 100 | 40 | 42 | 58 | 100 | – | 46 | 65 | 47 | 54 | 61 | 39 | 52 |
| Traditional to the area | | – | | – | | – | 25 | 54 | 38 | 53 | 77 | 82 | 40 | 50 |
| Better protection from termites | 100 | – | 40 | – | 17 | – | 51 | 15 | 26 | 26 | 23 | 6 | 39 | 13 |
| Clients prefer concrete-slab construction | - | – | | 27 | 42 | – | 76 | – | – | 19 | 15 | 14 | 32 | 9 |

[1]Based on estimated market populations of architects and builders designing and/or building one-story single-family residential homes.

Table 9—*Advantages most often anticipated for using underfloor plenum construction*

| Advantages expected | Market | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oak-Martinez | | Sacramento | | Fresno | | Los Angeles | | San Diego | | Phoenix | | Southwest[1] | |
| | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr |
| | *Percent* | | | | | | | | | | | | | |
| Warm floors | 22 | 4 | 47 | 7 | 14 | | 40 | | 19 | 5 | 15 | | 29 | 3 |
| More efficient heating and cooling | 33 | 25 | 38 | 7 | 36 | | 10 | 19 | 55 | 31 | 23 | 20 | 27 | 21 |
| Low profile appearance | 33 | 8 | 21 | 7 | 14 | 16 | 10 | | 19 | 9 | | | 18 | 5 |
| Elimination of ductwork | 11 | 29 | 38 | 19 | 14 | 16 | 10 | 6 | 19 | 5 | 8 | 6 | 14 | 13 |

[1] Based on estimated market populations of architects and builders designing and/or building one-story single-family residential homes.

Table 10—*Disadvantages most often anticipated for using underfloor plenum construction*

| Disadvantages expected | Market | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oak-Martinez | | Sacramento | | Fresno | | Los Angeles | | San Diego | | Phoenix | | Southwest[1] | |
| | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr | Arch | Bldr |
| | *Percent* | | | | | | | | | | | | | |
| Reservation on cost | 11 | 12 | 6 | 12 | 14 | | 40 | 31 | 36 | 17 | 46 | 41 | 28 | 22 |
| Question heating and cooling efficiency | 23 | 17 | 26 | 12 | — | — | 10 | 12 | 28 | 17 | 39 | | 21 | 12 |
| Local building codes | — | 8 | 21 | 12 | 14 | 32 | 20 | 6 | — | 17 | — | 6 | 9 | 10 |
| Poor access to underfloor area | 23 | 8 | 12 | — | — | — | — | — | 9 | 13 | — | — | 9 | 5 |

[1] Based on estimated market populations of architects and builders designing and/or building one-story single-family residential homes.



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Harpole, George B., and H. Edward Dickerhoof

1971. **Floor foundations: preferences of architects and builders in six Southwestern United States markets.** Berkeley, Calif., Pacific SW. Forest & Range Exp. Sta., 11 p., illus. (USDA Forest Serv. Res. Paper PSW-74)

Mail questionnaires and follow-up interviews were used to determine preferences among three types of floor foundations: concrete slab, wood crawl-space, and a new design that combines a low-profile wood floor with underfloor plenum. Crawl-space construction was preferred in the Sacramento and Oakland-Martinez markets; concrete slab was preferred in the Los Angeles, San Diego, and Phoenix markets. Preference was about evenly divided in the Fresno market. More than 60 percent of the respondents would consider the new underfloor plenum design.

*Oxford:* 833.11–(079.5):(79).
*Retrieval Terms:* floor foundations; builder preference; concrete slabs; wood frame with crawl space; wood floor (low-profile); Arizona; California.

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# LOW-LEVEL WIND MAXIMA in the 1969 San Mateo and Walker Fires

Bill C. Ryan George R. Ellis Donald V. Lust

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## The Authors

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A large void in the study of fire behavior is evident in the area of low-level wind maxima —sometimes called *low-level jets*. Byram (1954) studied the relationship of extreme fire behavior to wind profiles and established a classification of profile relation to fire behavior. That the presence of strong low-level wind maxima can greatly increase the rate of spread of forest fires is well known (Barad 1961). Most studies, however, have been prompted by interest in aircraft flight problems and in the relationship of low-level wind maxima to thunderstorm development: examples are papers by Means (1952), Curtis and Panofsky (1958), Pitchford and London (1962), and Bonner (1966). Much of the work has been focused on the low-level jet of the Great Plains, partly because this jet is both strong and prevalent east of the Rocky Mountains. Bonner (1968), in his evaluation of data from the U.S. Weather Bureau synoptic rawinsonde network for a 2-year period, suggested that the jet occurred much more often and was much stronger east of the Rockies than along the west coast. The west coast jet was considered different in other characteristics also. Data from Oakland and Santa Monica, California, show that speeds are much less and, unlike the condition east of the Rockies, northerly flow is more frequent than southerly flow. And although southerly jet flow was more prevalent at stations east of the Rockies, many of the stations also had a greater frequency of northerly jet flow than Oakland and Santa Monica. That low-level jet winds commonly occur in either direction is an important point to consider in determining possible mechanisms in their formation.

Although their occurrence is recorded at the observing stations relatively infrequently, the influence of low-level wind maxima on fire behavior is important. Also, statistics obtained from the few observing stations along the west coast may be somewhat misleading. Because the jet is characteristically small in vertical and horizontal extent, many occurrences may not be observed in the large-scale grid of upper-air observations.

The occurrence of strong surface and low-level winds during the San Mateo and Walker Fires *(fig. 1)* of August 1969 reemphasizes the great need to understand how and why these winds occur. Data collected during this period also make a worthwhile basis for study. We had hoped that analogous situations could be found in records of unforecast strong surface winds in southern California since 1957, but none was found. Several instances of morning east-to-southeast winds over the Cleveland National Forest in southern California were recorded, some apparently associated with dying tropical disturbances in northwest Mexico. Instances of strong north-to-northeast winds were usually the result of fast-moving short-wave troughs. A record of similar situation on May 27, 1960 refers to a low-level northerly jet peaking at 3,000-ft. altitude, the result of a rapid ridging behind a weak front. Strong north-to-northeast winds of August 27-30, 1962 in the mountains north of Los Angeles appear to resemble the August 1969 situation in low-level behavior, but the causal mechanism, a synoptic-scale invasion of cold air at middle levels, was easier to determine. On the Liebre Fire in the northwest corner of the Angeles National Forest, the strong localized northerly winds observed for a short time on June 22, 1968 were almost certainly due to a weak, fast-moving short-wave trough.

This paper reports a study in which the San Mateo and Walker Fires served as a focus for examination of low-level wind maxima. Possible causes in general and probable influences in these fires were investigated and are discussed. Not enough data were available to determine accurately the relative contributions of wind-producing mechanisms in these fires. Nevertheless, a description of how various mechanisms contributed or might have contributed may be valuable in future forecasts of fire weather and fire behavior.

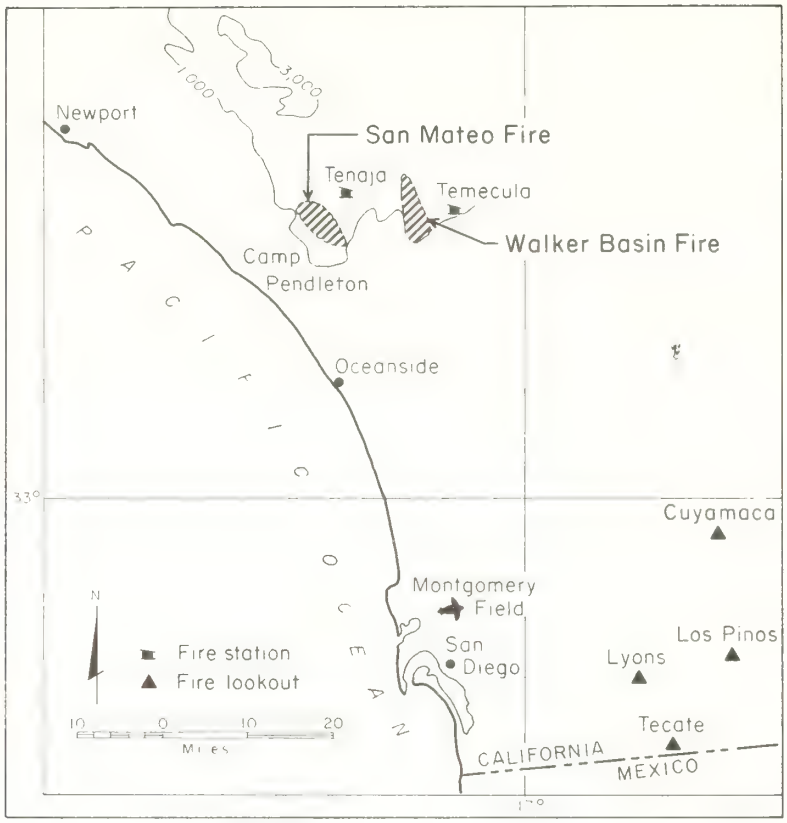


Figure 1—*San Mateo and Walker fire area.*

## THE SAN MATEO AND WALKER FIRES

The San Mateo Fire started during the afternoon of August 22 on Camp Pendleton military reservation in lower San Mateo Canyon and spread rapidly upcanyon and southeastward under strong northwesterly winds. Most of the spread was during the first afternoon. By night, winds had died down and fire spread was stopped on the southwest at De Luz Creek by the decrease in wind and fuel and increase in humidity, and on the northeast by rocky ridges and good fuel-breaks. During the next day, under light wind conditions, the fire spread slightly to a total of 16,849 acres.

The Walker Fire began south of Murietta in Walker Basin and burned rapidly southeastward during the afternoon and evening of August 22. Most of the acreage was burned during this time, but a few more acres on the west and southwest sectors burned on the 23rd. The 24th was quiet, and control was achieved on the morning of the 25th at a final area of 16,800 acres. There were also several other fires in the area during the period, including the Moosa Fire, which burned over 6,000 acres.

## WEATHER SITUATION

The fires were preceded by a long period of above-normal temperatures in southern California, owing to the influence of a large pressure ridge aloft extending from the Pacific over the central and western part of the United States (Dickson 1969). Conditions were hot and dry with extreme fire danger in the fire areas. On the morning of Friday, August 22, before the fires started, several of the lookouts reported strong winds generally from the northwest on the coastal side of the mountains and the northeast on the desert side.

Tecate Lookout, at 3,887 ft. on the Mexican border, estimated winds of 39 knots with gusts to 48 knots at 0800 and northwest at 39 knots at 1007 (all

times given are Pacific daylight saving time). At the same time, Cuyamaca at 6,500 ft. reported northwest winds at 17 knots with gusts to 25 knots. Lyons Lookout at 3,755 ft. reported northeast winds at 26 knots while Los Pinos at 4,800 ft. had northeast winds at 22 knots. The winds over San Diego's Montgomery Field (MYF) were quite strong by 1700 on August 21 *(fig. 2),* with the low-level maximum from the northwest at 19 knots at 2,000 ft. The winds increased, however, to 36 knots at 2,000 ft. at 1700 on August 22. Winds were still 24 knots at 5,000 ft. at 0500 on August 23, but dropped off rapidly later that morning and by 1700 the strongest wind reported below 10,000 ft. was 16 knots. The winds determined by pilot balloon observations *(fig. 3)* near the fire at the California Division of Forestry Fire Station in Temecula were similar to the winds at Montgomery Field; however, they showed several differences in detail in the lower level from the first observation at 2100 August 22 until the last at 1700 August 23. The maximum, however, during the interval was 22 knots between 4,000 and 5,000 ft. m.s.l. near 0030 on August 23. The maximum at Temecula occurred about 7-1/2 hours later and 3,000 ft. higher than at Montgomery Field. The winds weakened significantly by the 0800 observation on August 23.

Available upper-air data from rawinsonde observations in the area indicate that the winds were not as strong to the north. At 1700 on the 2lst, the winds at Montgomery Field were very different from those at Vandenberg Air Force Base (VBG) and Jackass Flats (UCC, near Las Vegas) as shown in *figure 4.* At Vandenberg Air Force Base and Jackass Flats they

Figure 3—*Winds (in knots) over Temecula, August 22-23, 1969. (Pacific daylight saving time.)*

were weak and disorganized whereas at Montgomery Field they were strong and consistently northwesterly. Unfortunately, data from San Nicolas Island (NSI) and Yuma (YUM) were missing. The difference between winds at Montgomery Field and Vandenburg Air Force Base was less but still evident at 1700 the next day *(fig. 5);* the winds at Montgomery Field were much stronger. Strong winds were also evident at 1700 on August 22 at San Nicholas Island, west of the fire area. At 1700 on the 23rd *(fig. 6)* winds over Montgomery Field had decreased considerably. The wind at 3,000 ft. had decreased to 8 knots, and the maximum wind was only 16 knots at 1,000 ft. *(fig. 2).* Winds were still strong, however, over San Nicolas Island and had increased over Vandenberg Air Force Base.

Figure 2— *Winds (in knots) over Montgomery Field (MYF) San Diego for August 21-23, 1969. (Pacific daylight saving time.)*

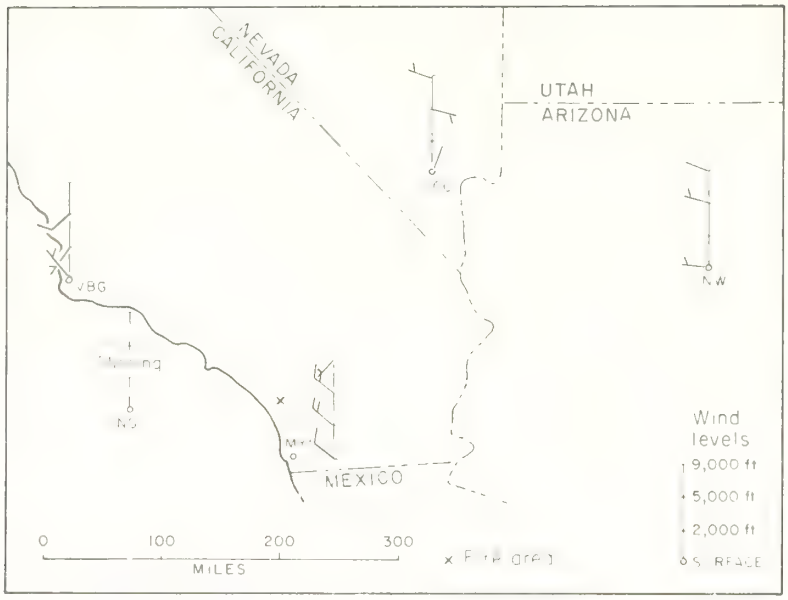


Figure 4—*Winds (in knots) at 1700 August 21, 1969. (Pacific daylight saving time.)*

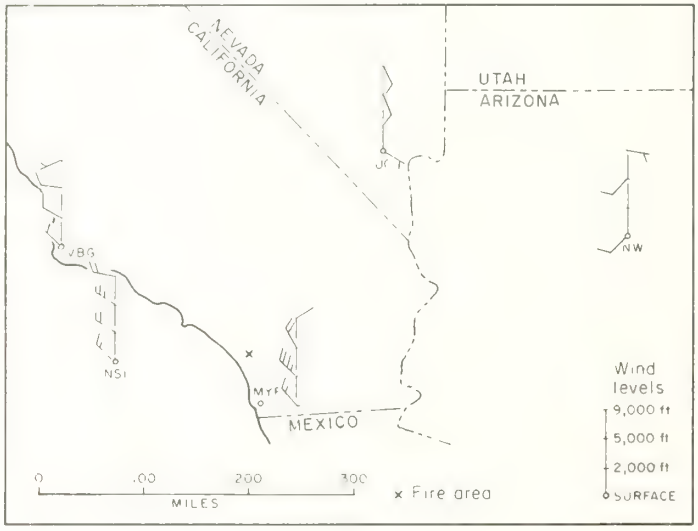


Figure 5—*Winds (in knots) at 1700 August 22, 1969. (Pacific daylight saving time.)*

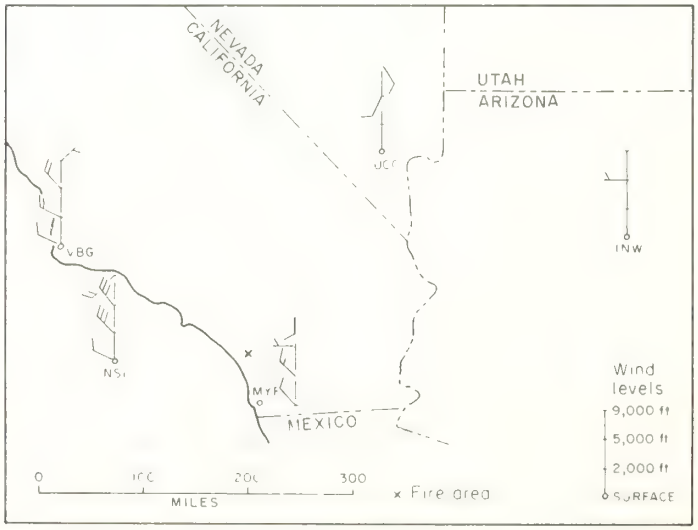


Figure 6—*Winds (in knots) at 1700 August 23, 1969. (Pacific daylight saving time.)*

A comparison of temperature and wind profiles for 1700 on August 21, 22, and 23 at Montgomery Field *(fig. 7)* showed the correspondence of inversion height and strength to maximum-wind height and strength. The temperatures as well as the windspeeds at the tops of the inversions on both August 21 and August 22 were very high. The temperatures were greater than 90°F. on August 22 and more than 95°F. on August 21 at heights of maximum temperature near 2,000 ft.

Changes of the wind profile from the afternoon of August 21 to the afternoon of August 23 at Montgomery Field are shown in *figure 8.* Winds were strong on August 2l, and the jet-nose was at about 2,000 ft. There was a great increase in the maximum wind by the afternoon of the 22nd, and the maximum was still at about 2,000 ft. The height of the maximum wind increased to about 5,000 ft. by the morning of August 23. The pilot-balloon observations *(fig. 9)* show that the maximum winds were already at 5,000 ft. by 2100 on the 22nd at Temecula. There was a rapid decrease of the wind at Temecula on the morning of the 23rd and in the afternoon sounding at Montgomery Field. The strong winds were low-level phenomena. Winds at 700 mb. in the area remained light during the entire period. They remained light southeasterly at Montgomery Field, very light from the southwest to the southeast at Vandenberg Air Force Base and southwesterly at San Nicolas Island.

## POSSIBLE WIND-PRODUCING MECHANISMS

The mechanisms that may have contributed to the low-level maxima observed in the San Mateo and Walker Fires vary in complexity and in probable degree of influence. We have included some mechanisms, and evaluations of their probable degrees of influence, in the discussion even though their influence may have been slight or only remotely possible. This was done in an attempt to include mechanisms that, although they seem to have little influence in this case, may be important in other similar situations.

### *Supergradient Wind*

A fairly subjective estimate of the gradient in the area of the fires *(fig. 10)* indicates that at 850 mb. the geostrophic wind and gradient wind were within a few knots of the observed windspeed.

The geostrophic wind is defined by the relationship:

$$V_g = \frac{g}{f}\frac{\partial z}{\partial n}$$

where $V_g$ is the geostrophic wind, g is the acceleration of gravity, f is the coriolis parameter ($2\omega\sin\phi$) which at 33°N. is 7.94 X $10^{-5}$ sec.$^{-1}$, and $\frac{\partial z}{\partial n}$ is the pressure-height contour gradient. Thus at the latitude of the study area, geostrophic winds at 20 knots, for example, would correspond to a contour gradient of about 13.5 meters per 100 miles. The winds could have been gradient because of packing of contours. Whether or not packing did occur cannot be determined because upper-air data density is not great enough. Curvature of flow is also not known accurately enough to determine how much the curvature would have made the gradient winds differ from the geostrophic. Comparison of successive streamline maps, however, indicates the trajectory of flow was anticyclonic in the fire area, and thus the gradient winds were greater than the geostrophic.

A comparison of winds from 5,000 ft. to 9,000 ft. over Montgomery Field with those over San Nicolas Island on August 22 at 1700 shows a great contrast in change of direction of windflow *(fig. 5).* The winds veered between 5,000 ft. and 9,000 ft. from 330/20 to 050/02 over Montgomery Field, but over San Nicolas Island the winds backed with height from 295/30 to 270/22. These changes with height affected the curvature of the windflow in the layer so that the winds changed from slightly anticyclonic at 5,000 ft. to greatly anticyclonic at 6,000 ft. and also caused the winds in the layer from 6,000 ft. to 9,000 ft. to converge near the southwestern corner of California. In this layer the anticyclonic curvature of the windflow is certainly significant and could indicate a gradient wind in the southwest corner of California that was stronger than geostrophic. The anticyclonic flow and the accompanying subsidence would have contributed to the strength of the inversion near the coast. Although the data are not sufficient to indicate definitely that supergradient winds occurred, this seems quite likely. Means (1952) writing of the low-level jet in the southern plains of the United States, says, "Wind speeds frequently appear to be greater than the expected geostrophic or gradient speeds." We know that this is not uncommon in the southern California mountains.

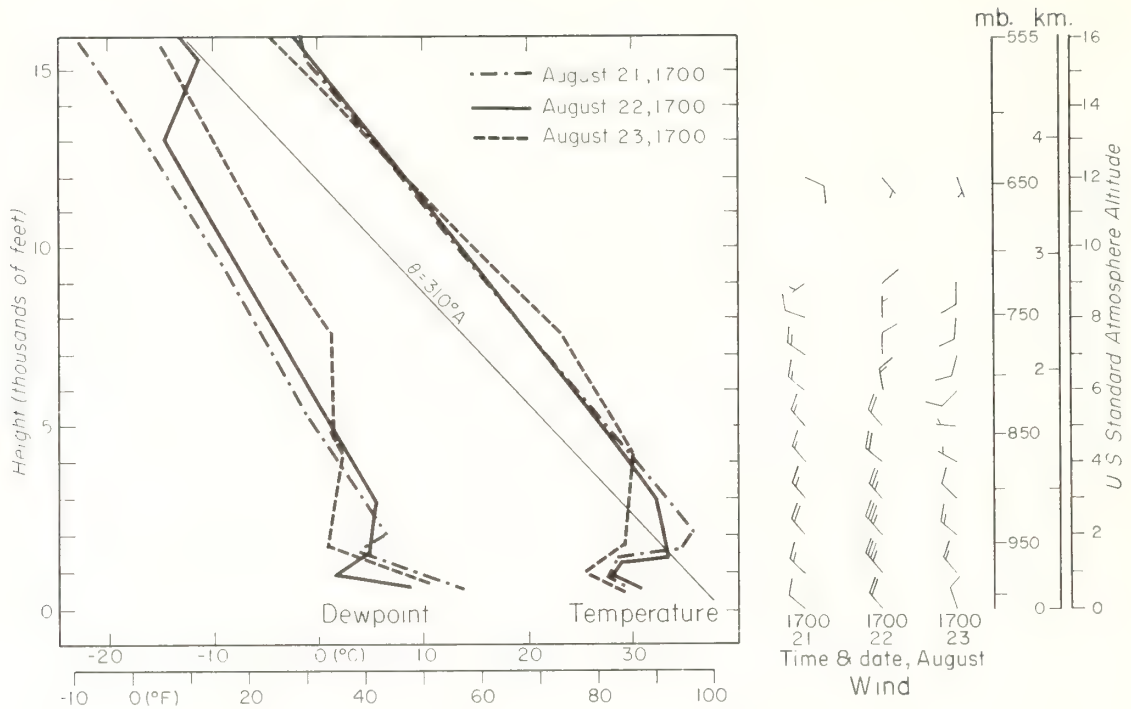


Figure 7—*Dewpoint, temperature, and wind profiles (in knots) at Montgomery Field (MYF). (Pacific daylight saving time.)*

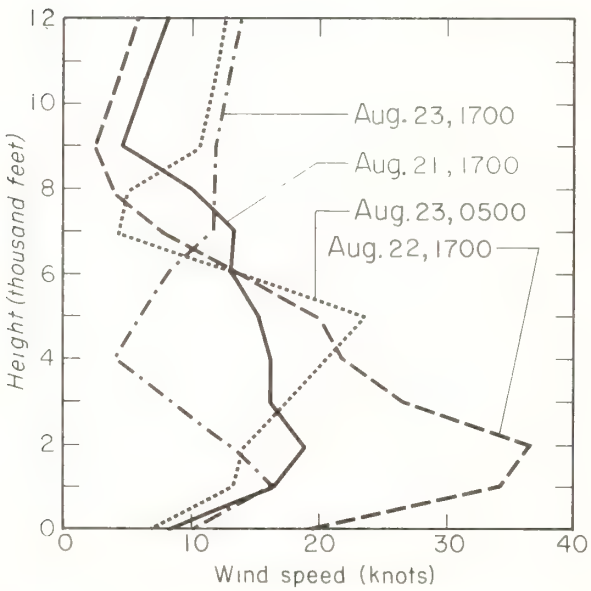


Figure 8—*Wind profiles for Montgomery Field (MYF). (Pacific daylight saving time.)*

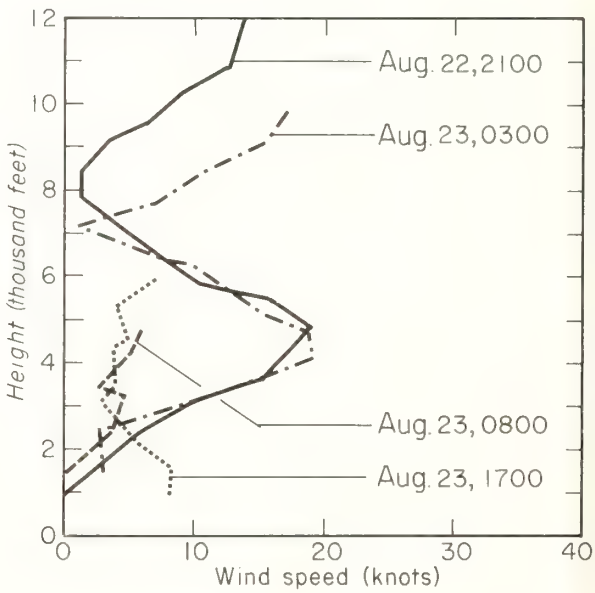


Figure 9—*Wind profiles at Temecula. Surface winds at 2100, 0030, 0300, and 0900 were light and variable. (Pacific daylight saving time.)*

## Easterly Wave and Low-Level Ridge

A small-scale inverted trough (a weak easterly wave disturbance) was moving westward along the Mexican border over southern Arizona and southern California, as indicated by a weak vorticity maximum and by windflow in the 6,000- to 9,000-foot layer. A sharp ridge nosed-up northeastwardly just off the coast. The inverted trough to the east and the ridge to the west appeared to cause a zone of convergence between and could have been an important factor in producing the strong winds. The strong low-level ridge of high pressure off the coast which seems to be somewhat the antithesis of the Catalina "Cyclonic" eddy (Coffin 1959) may also, by itself, be an indicator of strong low-level winds in that area. Unfortunately, these disturbances were too far south and too weak to document and examine in any detail. The unusual characters of this convergence zone, the low-level ridge and the low-level winds suggest cause and effect relationships and should be watched for in future analyses.

## Upper-Level Pressure Pattern

An examination of the pattern at 300 mb. indicates no jet stream near the area. There was, however, a weak low center that had apparently broken off earlier from a trough at that level and that remained for several days over extreme southeastern California. It is doubtful that this low pressure center could have had a significant effect on the low-level strong winds, considering that the 700-mb. and 500-mb. charts did not show such a feature.

## Absolute Vorticity Conservation

One possible reason for development of this variation in windspeed is the principle of absolute vorticity conservation. The principle can be described in simple qualitative terms. If we assume that the absolute vorticity, $\frac{\zeta+f}{D}$, is constant for individual columns of the atmosphere moving southward, then as f, the coriolis parameter, decreases with decreasing latitude, the vorticity relative to the earth, $\zeta$, must increase, and/or D, the column depth, must decrease. If D remains constant, the column must increase its relative vorticity as the column moves to the south. Relative vorticity can be defined in terms of natural coordinates:

$$\zeta = \frac{V}{r} + \frac{\partial V}{\partial n}$$

If the relative vorticity increases, owing mainly to an increase in shear, $\frac{\partial V}{\partial n}$, rather than curvature, $\frac{V}{r}$, then a high-speed current at the western boundary of the flow along the coastal ranges must develop. For the fire area, this analysis is of course hypothetical, because of the many assumptions made, such as the change of column depth and change of shear and curvature along the air trajectory. It is difficult to obtain more than a quite conjectural indication of its contribution. All that can be said is that it may have contributed.

## Inertial Oscillation

Another theory, advanced by Blackadar (1957) and applied to explain the formation of nocturnal

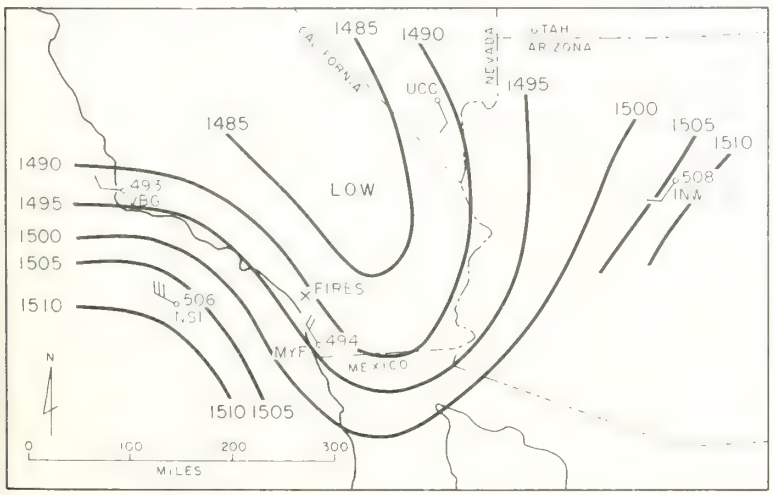


Figure 10-*Winds at the level of 850 millibars and height contours (meters) at 1700 August 22, 1969. (Pacific daylight saving time.)*

low-level wind maxima, is that windflow develops an inertial oscillation. As an inversion builds during the night, usually by radiational cooling of the earth's surface, the inversion insulates the windflow from the loss of energy by turbulence near the surface. As the loss of energy is decreased, the windspeed, as depicted by vector $V_1$ in *figure 11*, can increase to such a speed as that depicted by vector $V_2$. As the inversion is destroyed, usually by solar heating, the airflow can again mix to the surface; more energy is again lost due to turbulence near the surface. The windspeed then tends to decrease. Thus, there is actually an oscillation from windspeed that is less than geostrophic to greater than geostrophic, because of inertia, as the coupling by eddy turbulence is decreased and increased by the formation and destruction of the inversion. The change of coupling causes a change in the ageostrophic vector, $V_a$, as shown in *figure 11*. The low-level windspeed maxima as shown in *figure 7* do show a correspondence to the strength of the inversion. There are two aspects, however, in which this mechanism seems inadequate to fully explain the phenomenon. First, the supergradient winds should occur primarily at night, when the surface inversion is most developed. In the fires studied here the winds continued well into the day. Second, Blackadar (1957) suggested that the diurnal oscillations should be greatest at inland stations where coefficients of eddy viscosity are larger than over the ocean. Here, strong winds occurred at sea and inland near the coast. Nevertheless, this mechanism, or an oscillation mechanism similar to it, could have been at least partially responsible for the low-level wind maxima.

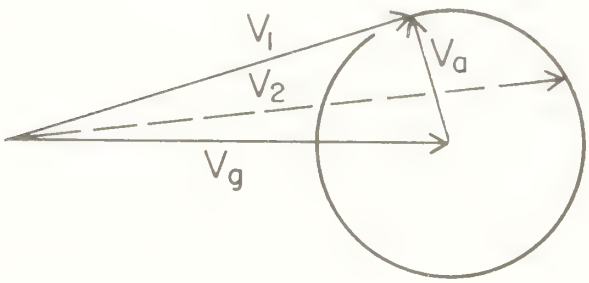


Figure 11—*Diagrammatic depiction of change of wind velocity from geostrophic, $V_g$, to less than geostrophic, $V_1$, owing to the friction of the earth's surface; and to greater than geostrophic, $V_2$, due to inertial oscillation. Here $V_a$ is the ageostrophic vector.*

## Channeling by Mountains

Channeling of flow by local mountains could be a factor in causing the strong winds. These winds were, in fact, nearly parallel to the Santa Ana Mountains, so that channeling may have been effective near the mountains, especially on the afternoons of August 21 and 22 when maximum winds were below mountain tops. This channeling is somewhat reflected in the convergence along the coast of the surface streamlines on Friday afternoon, *figure 12*. This could not be the entire reason for the winds because the jet is also seen over the ocean at San Nicolas Island. Also, at times, the strongest winds or nose of the profile occurred above the level of the mountains.

## Temperature Perturbations in the Inversion Layer

Another factor that has been suggested as a contributor to strong low-level winds is the mesoscale horizontal temperature gradient within the inversion layer as described by Edinger (1960) and Miller (1968). Miller found that perturbations of the inversion layer induced by differential heating between land and sea, and partially by topography, were chiefly responsible for the low-level winds he studied in the San Francisco Bay area. Perturbations in the inversion layer could also have been a factor in producing the strong winds along the Santa Ana Mountains. We have too few temperature soundings in the area, however, to determine variation on a small-enough scale to evaluate the contribution, if any, of this mechanism.

## Static Stability

The widespread thunderstorm and convective activity to the east and the strength of the inversion near the coast suggest that a well-developed wave or a vortex with a horizontal, north-south axis extended over the area. Either of these circulations, with upward motion to the southeast over eastern California and western Arizona, subsidence along the coast, and westerly flow at low levels, is in conformity with the synoptic situation and temperature distributions. The possible relation of the strong low-level winds to the thunderstorm and convective activity was considered. The winds, however, seemed to be too extensive, too anticyclonic, and too far from the convective activity to be very closely related to it.

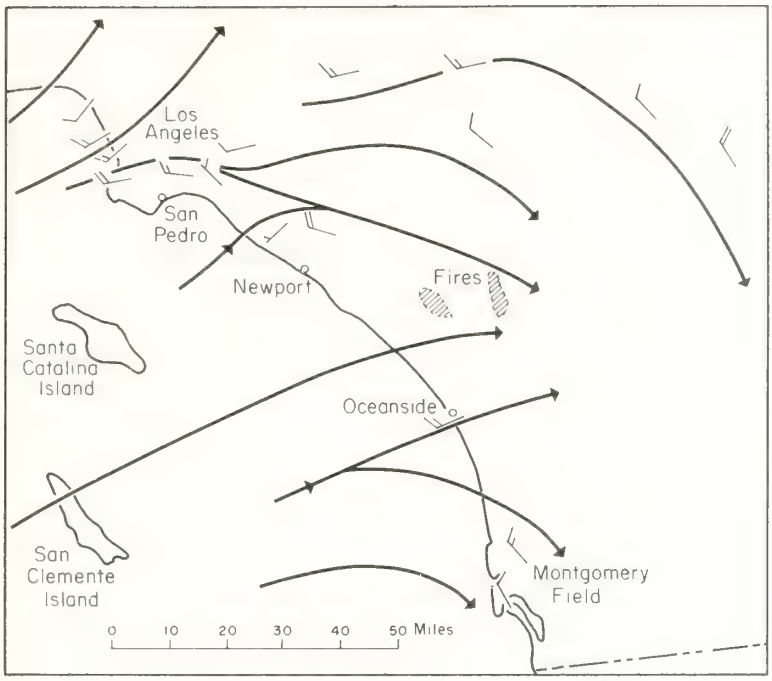


Figure 12—*Surface winds and wind flow, 1700 August 22, 1969. (Pacific daylight saving time.)*

### *Fire Interaction With the Atmosphere*

Another effect that is noteworthy is the contribution of the fire itself and its interaction with the atmosphere in bringing the strong winds to the surface. Clive M. Countryman, the fire behavior officer at the fires, observed: "On the Walker Fire during the evening of August 22, the winds around the fire area, including points at the same elevation as the fire, were very light. The fire itself was obviously being influenced by strong winds. It was also obvious that subsidence was taking place near the fire area; humidity was very low and temperatures high, particularly at the higher elevations."

## SUMMARY AND CONCLUSIONS

Ryan, Bill C., George R. Ellis, and Donald V. Lust
1971. **Low-level wind maxima in the 1969 San Mateo and Walker Fires.** Berkeley, Calif., Pacific SW. Forest & Range Exp. Sta. 10 p., illus. (USDA Forest Serv. Res. Paper PSW-75)

*Oxford:* 431.1:111.5:(794).
*Retrieval Terms:* fire weather; windflow; San Mateo Canyon Fire; Walker Basin Fire.

Strong low-level winds are not only important elements in fire behavior, but are significant in other problems. Therefore, the need to forecast the occurrence of such winds is great. In a case study in southern California, low-level wind jets that affected the severity of the San Mateo and Walker Basin Fires in August 1969 were studied. Because of the effects of a large pressure ridge aloft extending from the Pacific over the Western United States, the two fires were preceded by a long period of above-normal temperatures in southern California.

In the two fires, it appears that the low-level wind maxima generally developed on a scale too small to be easily forecast. Furthermore, there was a lack of data and experience to determine the cause of these winds or to develop forecast techniques necessary to

foresee their development or advection over an area of concern. Investigators have pointed out mechanisms that may result in strong winds under various conditions. In the fire studied here, it is probable that the strong winds were a result of a combination of mechanisms.

The mechanism most likely to have contributed to the occurrence of strong winds was a strong pressure gradient that seems to have been related to the existence of a low-level ridge to the west and an easterly wave to the east. Channeling of flow by mountain ranges or other topographic features is another quite obvious mechanism to be considered as a major contributor in this situation and probably in many others. The other potential factors discussed in this paper are not as obviously influential. Inertial oscillation, or an effect related to the tendency of airflow to conserve its absolute vorticity may also have operated. Other possible contributory mechanisms that have been suggested as causes in other cases and that may have contributed to the strong winds in this situation include perturbations in the height of the inversion layer and atmospheric static instability.

The list of effects that have been suggested as contributors to low-level wind maxima is quite long but very probably incomplete. An upper-air station network of greater density is needed to study and understand this phenomenon, but the experienced forecaster with knowledge of the relative probabilities under different circumstances can evaluate the chances of strong low-level maxima in each particular situation.

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The strong band of low-level winds that affected the severity of the San Mateo and Walker Fires in southern California on August 1969 was analyzed and studied. Mechanisms that could have caused or contributed to these winds and similar wind situations were evaluated and are discussed. Results show that the winds in this case were probably a product of several mechanisms in combination.

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PACIFIC SOUTHWEST
Forest and Range
Experiment Station

# PROFILES OF CALIFORNIA VEGETATION

William B. Critchfield

APR 14

USDA FOREST SERVICE RESEARCH PAPER PSW-76 /1971

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## The Author

**WILLIAM B. CRITCHFIELD,** a research geneticist, heads the Forest Service's Pioneer Research Unit on Hybridization and Evolution of Forest Trees, with headquarters in Berkeley, Calif. He is a native of Fargo, N.D. He earned a bachelor's degree (1949) in forestry and a doctorate (1956) in botany and genetics at the University of California, Berkeley. He then joined the Cabot Foundation for Botanical Research at Harvard University as a forest geneticist. From 1959 until his appointment as a pioneer research scientist in 1971, he was a member of the station's forest genetics research staff.

Assembled in this publication are 57 elevational profiles illustrating the natural vegetation of California. Collectively, they provide a picture of the dominant plant cover as it existed in the 1930's on about one-fifth of the State's land area *(table 1)*. The profiles sample the vegetation from Redding to San Diego, and include such extremes as the redwoods of Santa Cruz County, the subalpine forest of the Sierra Nevada crest, and the Joshua-tree "woodland" of the Mojave Desert.

These profiles were produced by the Vegetation Type Map (VTM) survey of California, conducted by the Forest Service between 1927 and the early 1940's. This survey was the most ambitious attempt ever made to describe the complex vegetation of the State. The VTM crews mapped on the ground nearly 40 million acres of California (about 40 percent of the land area), plus an adjacent corner of Nevada. About 7 million acres, mostly in southern California, were covered by 23 vegetation type maps published between 1932 and 1943. These maps were printed in color and accompanied by elevational profiles of the vegetation. Most of the remaining 33 million acres were eventually covered by less complete blue-line prints (Wieslander 1961), but the profiles drafted to accompany many of them were not published. Forty-three of the 57 profiles are published here for the first time, and the other 14 appeared earlier on vegetation maps.

In the decades since the VTM survey, the vegetation of many parts of California has changed dramatically. Natural succession, logging, and urbanization are responsible for some of these changes. The most drastic and widespread alterations in the vegetation, however, have been due to fires—especially in the mountains of southern California. To some extent, then, these profiles are a historical record, providing a base line against which changes in the plant cover can be assessed. They also have a more permanent value in illustrating patterns of vegetation, and how these patterns are associated with variable factors of the environment. The profiles are most useful in showing directly the relation between the composition of the dominant vegetation and such ecological factors as elevation, exposure, slope, and maritime influences.

None of the profiles is dated or initialled, but according to A. E. Wieslander, who directed the VTM survey throughout its existence, the artist was Michael N. Dobrotin (1896-1952). Dobrotin immigrated from the U.S.S.R. in the 1920's, and worked for the Forest Service after he was graduated from the University of California School of Forestry in 1933. He drew these profiles between 1934 and 1938, and later worked for the State of California. Although much of the artistry of his work has been lost in the process of reducing the profiles, the high quality of the originals is shown in the illustrations accompanying *table 2*.

## COVERAGE AND ARRANGEMENT

The VTM survey was part of the program of the California (now Pacific Southwest) Forest and Range Experiment Station. The original objective of the survey was to map the vegetation of all of California and part of Nevada, excluding deserts, cultivated land, and urban areas. After World War II, vegetation mapping of the State was reorganized and resumed on a smaller scale by the State Cooperative Soil-Vegetation Survey, which uses aerial-photo techniques and places greater emphasis on soil classification.

The mapping units of the VTM survey were the 15- and 30-minute topographic maps published by the U.S. Geological Survey, nearly all of them now superseded by greatly improved 7.5- and 15-minute maps. Each 30-minute quadrangle in California was assigned a number, beginning in the northeastern

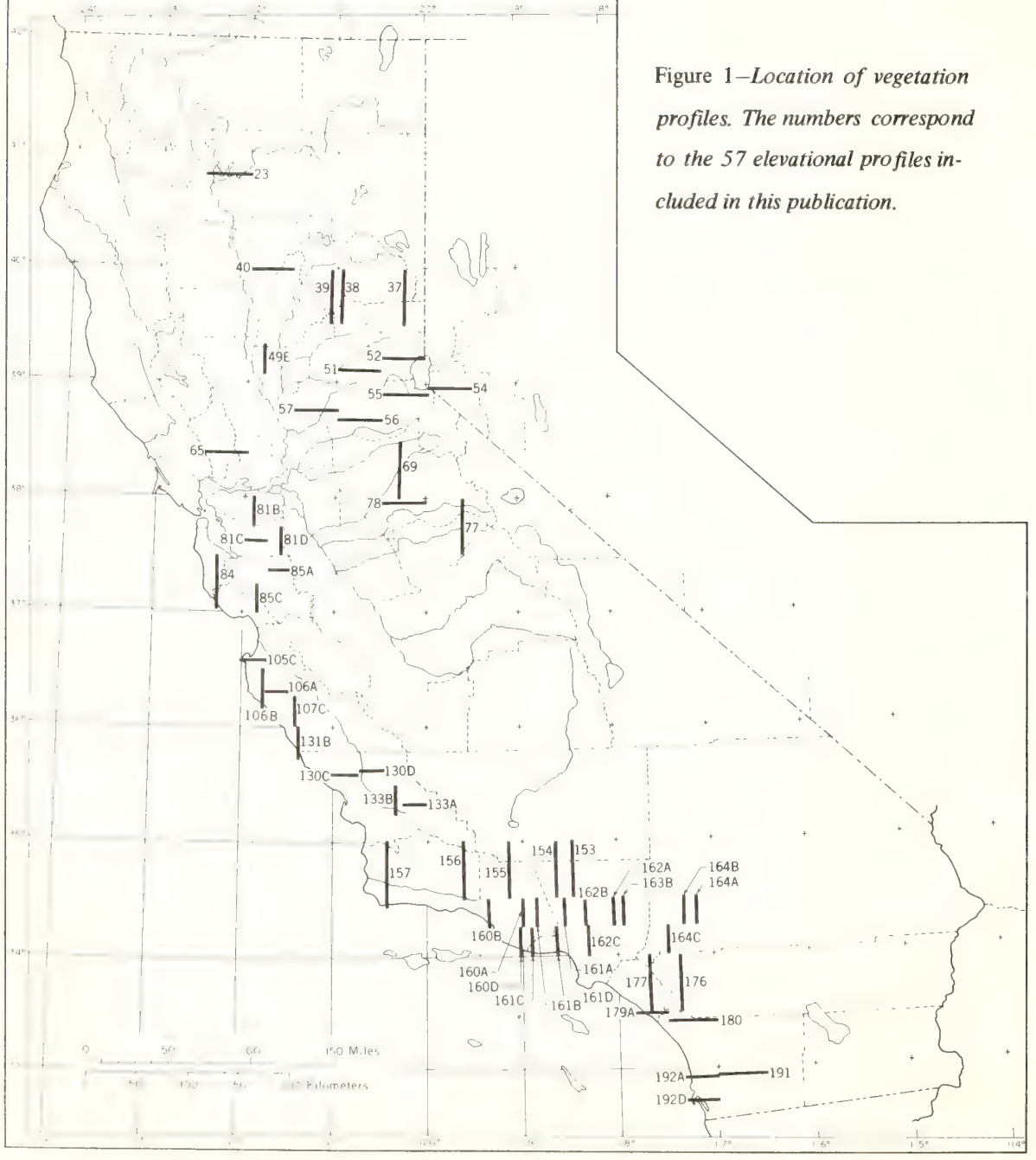


Figure 1—*Location of vegetation profiles. The numbers correspond to the 57 elevational profiles included in this publication.*

corner of the State. The four 15-minute quadrangles making up a 30-minute quadrangle were designated by adding to this number the letters A-D in the following sequence: NE (A), NW (B), SW (C), SE (D). These quadrangle designations have been retained here to identify the individual profiles.

The arrangement of the profiles follows the sequence in *table 1.* The 30-minute profiles precede the 15-minute profiles, and each group is arranged in numerical order. The two groups have been kept separate because they were drafted and are reproduced at different scales.

The profiles provide good coverage of the vegetation in the northern and central Sierra Nevada, and in the coastal mountains from Napa County south to the Mexican border *(fig. 1).* The principal forested regions sampled poorly or not at all are in the southern Sierra Nevada, the northern Coast Ranges, and northeastern California.

Other published profiles of various kinds fill some of these gaps. A series of generalized profiles across the Sierra Nevada includes one near Mount Whitney in the southern part of this range (Storer and Usinger 1963). A more detailed Sierra Nevada transect in the Yosemite region, near profile 77, extends east of the Sierra crest to Mono Lake (Hughes and Dunning 1949). The transects of Storie and Brown (1956), one across the northern Coast Ranges and the other in the central Sierra Nevada near VTM profiles 51-57, illustrate changes in soil types with elevation. Two of Knapp's schematic, large-scale profiles of evergreen, sclerophyllous vegetation types are outside the regions covered here—one on Santa Catalina Island and the other in the Garberville area of the northern Coast Ranges (Knapp 1961). A vegetation profile of the Lake Tahoe region of Nevada (Wilson 1941), probably drawn by M. N. Dobrotin, parallels profile 54 about 4 miles to the north.

The profiles can be used most effectively in the field by plotting the profile line on currently available topographic maps. The location of the profile lines is given in *table 1* to the nearest 0.1 minute of latitude or longitude. Occasional major topographic discrepancies can be expected; current maps are far more accurate than the maps available to the VTM survey.

## SCALE OF PROFILES

The horizontal scale is approximately 2 miles to the inch on the 30-minute profiles, and 1.18 miles to the inch on the 15-minute profiles. The exaggerated vertical scale, about 2.6 times the horizontal scale, is shown on the profiles in thousands of feet.

The length of the profiles in miles is tabulated below; the exceptions are profile lines extended beyond a quadrangle to the Pacific Ocean:

| | *Orientation* | *Length of profile (miles)* | *Exceptions* | |
|---|---|---|---|---|
| | | | *Profile No.* | *Length (miles)* |
| Group: | | | | |
| 30-minute | N-S | 34.6 | 157 | 39.1 |
| | E-W | 26.4 (northern) to 29.5 (southern) | | |
| 15-minute | N-S | 17.3 | 106B | 20.1 |
| | E-W | 13.7 (northern) to 14.5 (southern) | 192A | 16.6 |
| | | | 192D | 15.9 |

## VEGETATION TYPES

The VTM crews mapped the vegetation by direct sketching from ridgelines, peaks, and other vantage points. Their routes of travel, mostly afoot, are shown on maps in the VTM files. Visual estimation of the dominant vegetation was supplemented by an extensive system of sample plots. Field identification of plant species was backed up by the collection and subsequent study of large numbers of plant specimens. These specimens—25,000 to 30,000 in all—were added to the Herbarium of the University of California at Berkeley in 1954, and are still available for reference.

The dominant vegetation was classified by broad vegetation types. The numbers below the profile line on all but a few of the profiles designate the vegetation type. The types are described and illustrated in *table 2.*

This classification of the vegetation was designed to serve a variety of land-management objectives, including fire and flood control. Semidesert chaparral (*table 2:* type 8), for example, was similar in composition to ordinary chaparral (type 6), but differed in its lesser density and reduced fire hazard. Timberland chaparral (type 7) was intended to segregate those chaparral areas capable of growing commercial timber. Because of these multiple objectives, the types used by the VTM survey were not widely adopted in the classification of California's vegetation. They have been displaced in current usage by the plant communities of Munz and Keck (1949, 1950, 1959), but there are many parallels between the two classifications. Type 4 includes two of their communities: Coastal Sage Scrub and Sagebrush Scrub. Types 5 to 8 are all included in their Chaparral. Type 15 equals their Redwood Forest, and types 16 to 18 are roughly equivalent to their Yellow Pine Forest.

Within the broad vegetation and land-use types used by the VTM, the vegetation was mapped in subunits to a 40-acre minimum (10 acres for remnant timber and woodland types). The subunits were defined by the dominant plant species. Letter symbols designating the dominant species or other cover category (annuals, meadow, etc.) are shown on the profiles below the type number. These letter symbols are decoded in *table 3.*

A plant species was considered a dominant if it made up more than 20 percent of the plant cover, as viewed from above. In the case of commercial timber trees, the definition of dominance was based on numbers of stems above a minimum diameter. In composite types, having dominant vegetation not consisting exclusively of trees, shrubs, or herbaceous plants, the dominants were determined and listed separately for each category.

As a general rule the dominant plant species were listed in decreasing order of abundance, but there were so many exceptions as to almost invalidate this useful practice. In composite types, trees were listed before shrubs. Commercial timber trees were listed before other trees, in order of decreasing economic importance: redwood (R) and sugar pine (S) first, then yellow pines (Y, J), Douglas-fir (D), true firs ($\hat{W}$, $\hat{R}$), and incense-cedar (I). Shrubby communities adhered more closely to a sequence of decreasing abundance, but here too there were exceptions. Chamise (Af), for example, was almost always listed first in the vegetation type which it characterizes (*table 2:* type 5).

## PLANT NAMES AND SYMBOLS

All plant species appearing as dominants on the profiles are listed alphabetically in *table 4,* together with their letter symbols and an indication of their occurrence on the profiles. The letter symbols were based on the common names of trees (with some exceptions in *Quercus*) and the scientific names of other plants. If the symbol was based on a scientific name that is no longer accepted, this name is listed in parentheses. In a few instances, the symbol for a tree species derives from a common name no longer widely used, and these names are also listed to make the symbol understandable. Examples are Y = yellow pine *(Pinus ponderosa)* and H = horse-chestnut *(Aesculus californica).* Where two letters were used to designate a tree species, the second capital letter is shown at a smaller size on the profiles.

*Table 4* includes about 50 tree species, a few grasses (symbols underlined), a few other herbaceous plants (enumerated in *table 2:* type 2), and more than 100 shrubby and semishrubby species. Nomenclature follows Munz and Keck (1959), Munz (1968), and Little (1953). The biographical table in Munz and Keck (1959, p. 1551) was used for abbreviations of author names.

Many of the pictorial symbols of different kinds of plants are shown in *table 2.* Most tree species are represented by individual symbols, but there are a few exceptions. *Pinus ponderosa* (Y) and *P. jeffreyi* (J) have the same symbol, and so do *Quercus agrifolia* (A), and *Q. wislizenii* (W). The same tree species was sometimes illustrated by different symbols on different profiles (*Pinus radiata* on profiles 84 and 105C). Grasses and all other herbaceous plants were designated by the same symbol (*table 2:* type 2). Shrubby species of the "soft chaparral" type have a single symbol (*table 2:* type 4), and most shrubs of the "hard chaparral" type share one symbol (*table 2:* type 6). Exceptions

are the two species of *Adenostoma* in California; the widespread chamise (Af) and the more restricted redshank (As) each has its own symbol.

Field identifications of the VTM survey crews were usually good, but the published vegetation type maps include this disclaimer: "Where minor variations occur which cannot be distinguished in the mapping, the symbols used may represent not only the species indicated but also its varieties, and occasionally, even closely related species." In problem genera, such as *Arctostaphylos* and *Ceanothus*, the delimitation of species has changed considerably in the past few decades, and I have indicated some of these changes in footnotes to *table 4*.

## SUMMARY

Critchfield, William B.
1971. **Profiles of California vegetation.** Berkeley, Calif., Pacific SW. Forest & Range Exp. Sta., 54 p., illus. (USDA Forest Serv. Res. Paper PSW-76)

*Oxford:* 187(794).
*Retrieval Terms:* vegetation types; California; Sierra Nevada; southern California.

Assembled in this publication are 57 elevation profiles illustrating the natural vegetation of parts of montane California as it existed in the 1930's. The profiles are concentrated in the central and southern parts of the State, and include such vegetational extremes as the redwoods of Santa Cruz County, the subalpine forest of the Sierra Nevada crest, and the Joshua-tree "woodland" of the Mojave Desert.

The profiles were drawn by Michael N. Dobrotin for the U.S. Forest Service's Vegetation Type Map (VTM) survey, which mapped on the ground nearly half of the State's vegetation between 1927 and the early 1940's. Fourteen of the profiles were published on vegetation type maps between 1932 and 1943, and the rest are printed here for the first time. Each profile is oriented north-south or east-west, and covers a single 15- or 30-minute topographic quadrangle. The horizontal scale is 1.18–2 miles to the inch, and the exaggerated vertical scale is shown on the profiles.

In the decades since the VTM survey, the vegetation of many parts of California has been drastically altered by fire, logging, urbanization, and natural succession. The profiles provide both a historical record of the vegetation and a base line against which changes in the plant cover can be assessed. They also illustrate the association between vegetation patterns and variable factors of the environment, and show directly the relation between the composition of the dominant vegetation and such ecological factors as elevation, exposure, slope, and maritime influences.

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# TABLES

Table 1—*Index of vegetation profiles*

| Quadrangle | | | Profile location | |
|---|---|---|---|---|
| Number | Name | Date surveyed | Latitude (N) | Longitude (W) |
| | | 30-MINUTE QUADRANGLES | | |
| 23 | Redding[1] | 1932-33 | 40°48.0′ | 122°00′ to 122°30′ |
| 37 | Sierraville | 1934-36 | 39°30′ to 40°00′ | 120°15.0′ |
| 38 | Downieville | 1934-35 | 39°30′ to 40°00′ | 120°56.8′ |
| 39 | Bidwell Bar | 1933-34 | 39°30′ to 40°00′ | 121°04.0′ |
| 40 | Chico | 1933-34 | 39°59.1′ | 121°30′ to 122°00′ |
| 51 | Colfax | 1933-34 | 39°06.0′ | 120°30′ to 121°00′ |
| 52 | Truckee | 1934 | 39°13.3′ | 120°00′ to 120°30′ |
| 54 | Markleeville | 1934 | 38°56.5′ | 119°30′ to 120°00′ |
| 55 | Pyramid Peak | 1934 | 38°53.4′ | 120°00′ to 120°30′ |
| 56 | Placerville | 1931-34 | 38°39.8′ | 120°30′ to 121°00′ |
| 57 | Sacramento | 1931-34 | 38°45.1′ | 121°00′ to 121°30′ |
| 65 | Napa | 1932 | 38°23.1′ | 122°00′ to 122°30′ |
| 69 | Big Trees | 1935 | 38°00′ to 38°30′ | 120°18.3′ |
| 77 | Yosemite | 1935 | 37°30′ to 38°00′ | 119°35.7′ |
| 78 | Sonora | 1935-36 | 37°57.2′ | 120°00′ to 120°30′ |
| 84 | Santa Cruz | 1935-36 | 37°00′ to 37°30′ | 122°18.0′ |
| 153 | Elizabeth Lake[1] | 1928-34 | 34°30′ to 35°00′ | 118°28.6′ |
| 154 | Tejon | 1935 | 34°30′ to 35°00′ | 118°39.1′ |
| 155 | Mt. Pinos | 1930-34 | 34°30′ to 35°00′ | 119°10.1′ |
| 156 | Santa Ynez | 1935-36 | 34°30′ to 35°00′ | 119°38.5′ |
| 157 | Lompoc | 1930-35 | 34°30′ to 35°00′ | 120°27.1′ |
| 176 | Elsinore[1] | 1930-34 | 33°30′ to 34°00′ | 117°22.0′ |
| 177 | Corona[1] | 1930-34 | 33°30′ to 34°00′ | 117°41.0′ |
| 180 | San Luis Rey[1] | 1931 | 33°24.8′ | 117°00′ to 117°30′ |
| 191 | Cuyamaca | 1930-34 | 32°56.7′ | 116°30′ to 117°00′ |
| | | 15-MINUTE QUADRANGLES | | |
| 49E | Marysville Buttes | 1934 | 39°05′ to 39°20′ | 121°49.2′ |
| 81B | Mt. Diablo | 1932-37 | 37°45′ to 38°00′ | 121°54.9′ |
| 81C | Pleasanton | 1932 | 37°37.7′ | 121°45′ to 122°00′ |
| 81D | Tesla | 1932 | 37°30′ to 37°45′ | 121°36.3′ |
| 85A | Mt. Hamilton | 1931 | 37°20.7′ | 121°30′ to 121°45′ |
| 85C | New Almaden[1] | 1935-36 | 37°00′ to 37°15′ | 121°50.6′ |

Table 1—*Index of vegetation profiles,* continued

| Quadrangle | | | Profile location | |
|---|---|---|---|---|
| Number | Name | Date surveyed | Latitude (N) | Longitude (W) |
| | | 15-MINUTE QUADRANGLES | | |
| 105C | Monterey | 1915, 1930-32 | 36°34.8′ | 121°45′ to 122°00′ |
| 106A | Jamesburg | 1930-32 | 36°18.3′ | 121°30′ to 121°45′ |
| 106B | Point Sur | 1929-32 | 36°15′ to 36°30′ | 121°47.5′ |
| 107C | Junipero Serra | 1929-32 | 36°00′ to 36°15′ | 121°25.1′ |
| 130C | Adelaida | 1937 | 35°36.2′ | 120°45′ to 121°00′ |
| 130D | Paso Robles | 1937 | 35°37.2′ | 120°30′ to 120°45′ |
| 131B | Cape San Martin | 1929-30 | 35°45′ to 36°00′ | 121°23.3′ |
| 133A | La Panza | 1937 | 35°19.5′ | 120°00′ to 120°15′ |
| 133B | Pozo | 1936-37 | 35°15′ to 35°30′ | 120°21.1′ |
| 160A | Santa Paula | 1930-34 | 34°15′ to 34°30′ | 119°00.5′ |
| 160B | Ventura | 1930-34 | 34°15′ to 34°30′ | 119°22.0′ |
| 160D | Hueneme | 1931-34 | 34°00′ to 34°15′ | 119°01.3′ |
| 161A | Santa Susana[1] | 1928-34 | 34°15′ to 34°30′ | 118°33.5′ |
| 161B | Piru[1] | 1930-34 | 34°15′ to 34°30′ | 118°50.8′ |
| 161C | Triunfo Pass[1] | 1930-34 | 34°00′ to 34°15′ | 118°55.0′ |
| 161D | Calabasas[1] | 1930-34 | 34°00′ to 34°15′ | 118°39.1′ |
| 162A | Tujunga[1] | 1928-33 | 34°15′ to 34°30′ | 118°02.3′ |
| 162B | San Fernando[1] | 1928-34 | 34°15′ to 34°30′ | 118°19.8′ |
| 162C | Santa Monica | 1930-33 | 34°00′ to 34°15′ | 118°18.8′ |
| 163B | Rock Creek[1] | 1928-33 | 34°15′ to 34°30′ | 117°56.0′ |
| 164A | Deep Creek | 1935 | 34°15′ to 34°30′ | 117°10.7′ |
| 164B | Hesperia | 1935 | 34°15′ to 34°30′ | 117°18.3′ |
| 164C | San Bernardino[1] | 1929-30 | 34°00′ to 34°15′ | 117°29.0′ |
| 179A | Capistrano | 1931 | 33°29.8′ | 117°30′ to 117°45′ |
| 192A | La Jolla | 1931 | 32°55.1′ | 117°00′ to 117°15′ |
| 192D | San Diego | 1931 | 32°43.3′ | 117°00′ to 117°15′ |

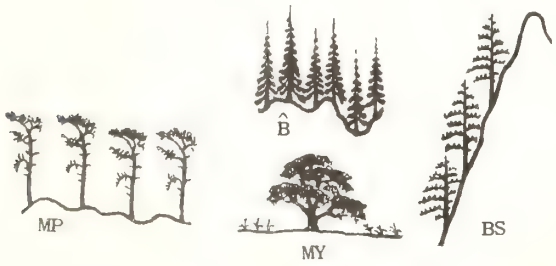
[1]Profile published with vegetation type map of quadrangle. Of the 23 published profiles, 14 are still available and are included here. Their publication dates were: 1934 - 164C; 1936 - 162B; 1937 - 153, 161A, 162A, 163B; 1938 - 176, 161B, 161D; 1939 - 23, 161C; 1940 - 177; 1942 - 85C; 1943 - 180.

Table 2–*Key to vegetation types*

| Type | Description and symbol |
|---|---|
| 1 | *Barren (Ba):* Areas which are practically devoid of vegetation, including areas typed as desert (De).<br>None |
| 2 | *Grassland (Gr):* Uncultivated areas with vegetation of grasses and associated low herbaceous plants. Also included here are meadows (Md) and vegetation dominated by a wide variety of non-woody plants (Eci, Emo, Hgr, Mhi, Pta, Sca, Skt, Wm).<br> |
| 3 | *Cultivated or urban (Cu, Res):* Cultivated or recently cultivated lands, regularly cropped natural hay lands, irrigated pastures, and residential and industrial areas.<br> <br>Res Cu |
| 4 | *Sagebrush:* Associations of thinly branched shrubs with soft, brittle wood. Characteristic genera are *Artemisia, Salvia, Eriogonum,* and *Baccharis.*<br> |
| 5 | *Chamise chaparral:* Chaparral associations in which chamise (Af) is one of the dominant species.<br> <br>Af |
| 6 | *Chaparral:* Dense associations of thickly branched, hard-woody shrubs. Characteristic genera are *Arctostaphylos, Ceanothus,* and the shrubby species and forms of *Quercus.*<br> |

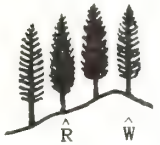
| Type | Description and symbol |
|---|---|
| 7 | *Timberland chaparral:* Chaparral associations occupying areas capable of growing commercial timber trees, and including at least one dominant shrub commonly associated with timber trees. In practice, the use of this type was mostly confined to Sierra Nevada chaparral, particularly at middle and upper elevations.<br>Same as type 6 |
| 8 | *Semidesert chaparral:* Open chaparral associations, usually bordering the desert and lacking the dense, uninterrupted cover of the chaparral type proper (type 6). Characteristic genera are the same as in type 6, plus *Cercocarpus.*<br> |
| 9 | *Woodland-chaparral:* Open stands of broad-leaved trees and Digger pine (DP) with intervening spaces occupied by shrubs of the chaparral types (5-8); includes both uniform mixtures of woodland and chaparral, and mosaics–areas of the two types too small to map.<br> <br>DP B |
| 10 | *Woodland-sagebrush:* Open stands of broad-leaved trees and Digger pine (DP) with intervening spaces occupied by species of the sagebrush type (4); includes both mixtures and mosaics, as in type 9.<br> <br>A |

Table 2—*Key to vegetation types,* continued

| Type | Description and symbol |
|---|---|
| 11 | *Woodland-grass:* Open stands of broad-leaved trees and Digger pine (DP) with intervening spaces occupied by grasses and other low herbaceous vegetation of type 2; includes both mixtures and mosaics, as in types 9 and 10. |
| 12 | *Woodland:* Stands of broad-leaved trees, Digger pine (DP), or both, forming a closed or nearly closed canopy; includes riparian woodland. |
| 13 | *Pinyon-juniper:* Associations which include pinyon pine (P) or junipers (Jc, Jo, Ju) among the dominants. |
| 14 | *Miscellaneous conifers:* Associations in which at least one of the minor coniferous tree species ($\hat{B}$, DY, MY, SY, TY, BP, CP, K, MP, TP, BS, and sometimes DP) is a dominant.   |

| Type | Description and symbol |
|---|---|
| 15 | *Redwood and redwood/Douglas-fir:* Forests in which redwood (R) alone or redwood and Douglas-fir (D) are among the dominants. |
| 16 | *Douglas-fir and Douglas-fir/fir:* Forests with Douglas-fir (D), or Douglas-fir and white fir ($\hat{W}$) among the dominant species, and not including redwood (R) or pines (J, S, Y) among the dominants. |
| 17 | *Pine and pine/Douglas-fir:* Forests in which one or more of the commercially important pines (J, S, Y) are among the dominant species, with or without Douglas-fir (D). |
| 18 | *Pine/fir and pine/Douglas-fir/fir:* Forests in which pines (J, S, Y) and firs ($\hat{R}$, $\hat{W}$) are among the dominants, with or without Douglas-fir (D). |

Table 2—*Key to vegetation types*, continued

| Type | Description and symbol |
|---|---|
| 19 | *Fir:* Forests consisting mostly of true firs ($\hat{R}$, $\hat{W}$).   |
| 21 | *Plantations:* Primarily species of *Eucalyptus* (Eu). |

| Type | Description and symbol |
|---|---|
| 20,22 | *High-elevation and subalpine coniferous forest:* Forests in which one or more of the following conifers are dominant: lodgepole pine (L), western white pine ($W^1$), whitebark pine (WP), limber pine (LP), mountain hemlock (HM). |

Table 3—*Alphabetical key to letter symbols of plant names and other ground-cover designations*

| Symbol | Plant name or other designation | Symbol | Plant name or other designation | Symbol | Plant name or other designation |
|---|---|---|---|---|---|
| A | Quercus agrifolia | Apa | Artemisia tridentata var. parishii | Aw | Arctostaphylos obispoensis |
| $\bar{A}$ | Populus tremuloides | Api | Arctostaphylos pilosula | B | Quercus kelloggii |
| A | Alnus rhombifolia | Apm | Arctostaphylos pumila | $\bar{B}$ | Populus trichocarpa |
| Aaa | Arctostaphylos auriculata | Aps | Arctostaphylos mewukka | $\hat{B}$ | Abies bracteata |
| Aan | Arctostaphylos pechoensis var. viridissima | Apy | Arctostaphylos parryana | Ba | barren |
| Aar | Artemisia arbuscula | Ar | Arctostaphylos rudis | Bh | Bromus mollis |
| Ab | Xylococcus bicolor | Arc | Artemisia cana | BP | Pinus muricata |
| Ac | Artemisia californica | As | Adenostoma sparsifolium | Bp | Baccharis pilularis |
| Acn | Arctostaphylos canescens | Ase | Arctostaphylos nummularia var. sensitiva | Br | Bromus diandrus |
| Adr | Artemisia dracunculus | Ast | Arctostaphylos stanfordiana | Bru | Bromus rubens |
| Af | Adenostoma fasciculatum | At | Arctostaphylos tomentosa | BS | Pseudotsuga macrocarpa |
| Ag | Arctostaphylos glauca | Atb | Atriplex lentiformis ssp. breweri | BT | Sequoia gigantea |
| Agl | Arctostaphylos glandulosa | Atc | Atriplex canescens | Bv | Baccharis viminea |
| Alo | Allenrolfia occidentalis | Ate | Alnus tenuifolia | C | Quercus chrysolepis |
| Am | Arctostaphlos manzanita | Atl | Atriplex lentiformis | Cb | Cercocarpus betuloides |
| Ama | Arctostaphylos mariposa | Atp | Atriplex polycarpa | Cc | Ceanothus cuneatus |
| An | Arctostaphylos nevadensis | Atr | Artemisia tridentata | Cch | Castanopsis chrysophylla (shrub form) |
| Ani | Arctostaphylos nissenana | AV | Avena sp. | Cco | Ceanothus cordulatus |
| Ann | annuals | Av | Arctostaphylos viscida | Ccr | Ceanothus crassifolius |
| Ap | Arctostaphylos patula | AVb | Avena barbata | Cd | Ceanothus leucodermis |

Table 3—*Alphabetical key to letter symbols of plant names and other ground-cover designations,* continued

| Symbol | Plant name or other designation | Symbol | Plant name or other designation | Symbol | Plant name or other designation |
|---|---|---|---|---|---|
| Cde | Ceanothus dentatus | Eci | Erodium cicutarium | Lpu | Leptodactylon pungens |
| Cec | Cercis occidentalis | Ecr | Eriodictyon crassifolium | Lpx | Lupinus sp. |
| Cf | Chamaebatia foliolosa | Ee | Haplopappus ericoides | Ls | Lotus scoparius |
| Cg | Ceanothus greggii | Ef | Eriogonum fasciculatum | Lsq | Lepidospartum squamatum |
| Cgp | Ceanothus greggii var. perplexans | Efc | Eriogonum cinerium | Lsu | Lonicera subspicata var. johnstonii |
| Chb | Haplopappus bloomeri | Emo | Erodium moschatum | Lt | Larrea tridentata |
| Chn | Chrysothamnus nauseosus | Enc | Encelia californica | M | Arbutus menziesii |
| Chr | Chrysothamnus sp. | Enf | Encelia farinosa | M | Acer macrophyllum |
| Chv | Chrysothamnus viscidiflorus | Epa | Haplopappus palmeri | Md | meadow |
| Ci | Ceanothus integerrimus | Epi | Haplopappus pinifolius | Mhi | Medicago polymorpha |
| Cj | Ceanothus jepsonii | Epv | Ephedra viridis | MP | Pinus radiata |
| Cl | Cercocarpus ledifolius | Eu | Eucalyptus sp. | MY | Cupressus macrocarpa |
| Cm | Ceanothus megacarpus | Ew | Eriogonum wrightii | Ng | Nicotiana glauca |
| Cn | Cornus nuttallii | F | Populus fremontii | Ox | Opuntia sp. |
| Co | Ceanothus oliganthus | Fc | Fremontodendron californicum | P | Pinus monophylla |
| Cof | Corethrogyne filaginifolia | Fd | Fraxinus dipetala | Pa | Heteromeles arbutifolia |
| CP | Pinus coulteri | Fm | Festuca megalura | Pan | Penstemon antirrhinoides |
| Cpa | Ceanothus palmeri | Gf | Garrya fremontii | Pe | Prunus emarginata |
| Cpl | Ceanothus papillosus | Gfl | Garrya flavescens | Pf | Prunus fasciculata |
| Cpo | Ceanothus prostratus | Gr | grasses | Pg | Purshia glandulosa |
| Cpr | Ceanothus parryi | Gsa | Gutierrezia sarothrae | Pi | Prunus ilicifolia |
| Cpv | Ceanothus parvifolius | Gv | Garrya veatchii | Pm | Pickeringia montana |
| Cri | Ceanothus rigidus | H | Aesculus californica | Pse | Pluchea sericea |
| Cs | Castanopsis sempervirens | Hd | Holodiscus discolor | Pt | Purshia tridentata |
| Cso | Ceanothus sorediatus | Hgr | Helianthus gracilentus | Pta | Pteridium aquilinum var. pubescens |
| Csp | Ceanothus spinosus | HM, Hm | Tsuga mertensiana | Qa | Quercus agrifolia (shrub form) |
| Ct | Ceanothus thyrsiflorus | Hm | Hordeum sp. | Qc | Quercus chrysolepis (shrub form) |
| Cto | Ceanothus tomentosus | Hys | Hymenoclea salsola | QD | Quercus Xalvordiana |
| Cu | cultivated | I | Libocedrus decurrens | Qd | Quercus dumosa |
| Cv | Ceanothus velutinus | J | Pinus jeffreyi | Qdu | Quercus durata |
| Cve | Ceanothus verrucosus | Jc | Juniperus californica | Qgb | Quercus garryana var. breweri |
| D | Pseudotsuga menziesii | Jo | Juniperus occidentalis | Qgs | Quercus garryana var. semota |
| D' | Quercus douglasii | Ju | Juniperus osteosperma | Qk | Quercus kelloggii (shrub form) |
| De | desert | K | Pinus attenuata | Qv | Quercus vaccinifolia |
| DIs | Distichlis spicata | L | Pinus contorta | Qw | Quercus wislizenii (shrub form) |
| DP | Pinus sabiniana | L' | Umbellularia californica | R | Sequoia sempervirens |
| Dr | Dendromecon rigida | La | Lupinus albifrons | R̂ | Abies magnifica |
| DY | Cupressus sargentii | Ld | Lithocarpus densiflorus (shrub form) | Rc | Rhamnus californica |
| E | Quercus engelmannii | Lde | Lithocarpus densiflorus var. echinoides | Rci | Rhamnus crocea var. ilicifolia |
| Ec | Eriodictyon californicum | LP | Pinus flexilis | Rd | Rhus diversiloba |

Table 3–*Alphabetical key to letter symbols of plant names and other ground-cover designations,* continued

| Symbol | Plant name or other designation | Symbol | Plant name or other designation | Symbol | Plant name or other designation |
|---|---|---|---|---|---|
| Res | residential (and other urban use) | Sli | Haplopappus linearifolius | Vo | Vaccinium ovatum |
| Ri | Rhus integrifolia | Sm | Salvia mellifera | W | Quercus wislizenii |
| Rl | Rhus laurina | So | Styrax officinalis var. californica | W' | Pinus monticola |
| S | Pinus lambertiana | SY | Cupressus sargentii | Ŵ | Abies concolor |
| S̄ | Platanus racemosa | Sx | Salix sp. | WC | Juglans californica |
| Sa | Salvia apiana | T | Lithocarpus densiflorus | Wm | Wyethia mollis |
| Saa | Salicornia virginica | Tc | Tetradymia canescens | WP | Pinus albicaulis |
| Sca | Scirpus acutus | TP | Pinus torreyana | Y | Pinus ponderosa |
| Scr | Salvia dorrii | TY | Cupressus forbesii | YB | Yucca brevifolia |
| Sg | Sambucus caerulea | Uc | Umbellularia californica (shrub form) | Ym | Yucca schidigera |
| Skt | Salsola pestifera | V | Quercus lobata | Yw | Yucca whipplei |
| Sl | Salvia leucophylla | | | | |

Table 4–*Plant names and occurrence on profiles*

| Scientific name | Symbol | Common name | Occurrence[1] |
|---|---|---|---|
| *Abies bracteata* D. Don | B̂ | bristlecone fir, Santa Lucia fir | 106A |
| *A. concolor* (Gord. & Glend.) Lindl. | Ŵ | white fir | SN, SC |
| *A. magnifica* A. Murr. | R̂ | California red fir | SN |
| *Acer macrophyllum* Pursh | M | bigleaf maple | SN, CR, SC |
| *Adenostoma fasciculatum* H. & A. | Af | chamise | SN, CR, SC |
| *A. sparsifolium* Torr. | As | redshank, ribbonwood | 161C, D |
| *Aesculus californica* (Spach) Nutt. | H | California buckeye, horse-chestnut | SN, CR, SC |
| *Allenrolfia occidentalis* (Wats.) Kuntze | Alo | bush pickleweed, iodine bush | 156 |
| *Alnus rhombifolia* Nutt. | A | white alder | SN, CR, SC |
| *A. tenuifolia* Nutt. | Ate | mountain alder, thinleaf alder | 52 |
| *Arbutus menziesii* Pursh | M | Pacific madrone | CR |
| *Arctostaphylos auriculata* Eastw. *(A. andersonii* var. *auriculata* Jeps.) | Aaa | | 81B |
| *A. canescens* Eastw.[2] | Acn | hoary manzanita | CR |
| *A. glandulosa* Eastw. | Agl | Eastwood manzanita | CR, SC |
| *A. glauca* Lindl. | Ag | bigberry manzanita | CR, SC |
| *A. manzanita* Parry | Am | common manzanita | 65, 81B |
| *A. mariposa* Dudl. | Ama | Mariposa manzanita | 77, 78 |
| *A. mewukka* Merriam *(A. pastillosa* Jeps.) | Aps | Indian manzanita | 51, 69 |

Table 4—*Plant names and occurrence on profiles,* continued

| Scientific name | Symbol | Common name | Occurrence[1] |
|---|---|---|---|
| *A. nevadensis* Gray | An | pinemat manzanita | SN |
| *A. nissenana* Merriam | Ani | Eldorado manzanita | 56 |
| *A. nummularia* var. *sensitiva* (Jeps.) McMinn *(A. sensitiva* Jeps.) | Ase | littleberry manzanita | 84 |
| *A. obispoensis* Eastw. | Aw | serpentine manzanita | 130C, 131B |
| *A. parryana* Lemmon | Apy | Parry manzanita | 155 |
| *A. patula* Greene | Ap | greenleaf manzanita | SN |
| *A. pechoensis* var. *viridissima* Eastw. *(A. andersonii* Gray*)* | Aan | Lompoc manzanita | 157 |
| *A. pilosula* Jeps. & Wies. | Api | La Panza manzanita | 133A |
| *A. pumila* Nutt. | Apm | dune manzanita | 105C |
| *A. rudis* Jeps. & Wies. | Ar | shagbark manzanita | 157 |
| *A. stanfordiana* Parry | Ast | Stanford manzanita | 65 |
| *A. tomentosa* (Pursh) Lindl.[3] | At | woollyleaf manzanita | CR, SC |
| *A. viscida* Parry | Av | whiteleaf manzanita | SN |
| *Artemisia arbuscula* Nutt. | Aar | low sagebrush | 37 |
| *A. californica* Less. | Ac | California sagebrush, coast sagebrush | CR, SC |
| *A. cana* Pursh | Arc | hoary sagebrush | 37 |
| *A. dracunculus* L. | Adr | tarragon | 177 |
| *A. tridentata* Nutt. | Atr | big sagebrush | SN, SC |
| *A. tridentata* var. *parishii* (Gray) Jeps. | Apa | | 156 |
| *Atriplex canescens* (Pursh) Nutt. | Atc | wingscale, fourwing saltbush | 156 |
| *A. lentiformis* (Torr.) Wats. | Atl | lenscale | 161B |
| *A. lentiformis* ssp. *breweri* (Wats.) Hall & Clem. *(A. breweri* Wats.) | Atb | | 160B |
| *A. polycarpa* (Torr.) Wats. | Atp | allscale | 156 |
| *Avena* sp.[4] | AV | oats | SC |
| *A. barbata* Brot.[4] | AVb | slender wild oats | CR |
| *Baccharis pilularis* DC. | Bp | chaparral broom, coyote brush | CR, SC |
| *B. viminea* DC. | Bv | mule fat | CR, SC |
| *Bromus mollis* L. (*B. hordeaceus* L.)[4] | Bh | soft chess | CR, SC |
| *B. diandrus* Roth (*B. rigidus* Roth)[4] | Br | ripgut brome | CR |
| *B. rubens* L.[4] | Bru | red brome | CR, SC |
| *Castanopsis chrysophylla* (Dougl.) A. DC. (shrub form) | Cch | golden chinquapin | 84 |
| *C. sempervirens* (Kell.) Dudl. | Cs | bush chinquapin, Sierra chinquapin | SN |
| *Ceanothus cordulatus* Kell. | Cco | mountain whitethorn, snowbush | SN |
| *C. crassifolius* Torr. | Ccr | hoaryleaf ceanothus | SC |
| *C. cuneatus* (Hook.) Nutt. | Cc | buckbrush, wedgeleaf ceanothus | SN, CR, SC |

Table 4—*Plant names and occurrence on profiles,* continued

| Scientific name | Symbol | Common name | Occurrence[1] |
|---|---|---|---|
| *C. dentatus* T. & G.[5] | Cde | cropleaf ceanothus | 133B |
| *C. greggii* Gray | Cg | desert ceanothus | SC |
| *C. greggii* var. *perplexans* (Trel.) Jeps. | Cgp | cupleaf ceanothus | 191 |
| *C. integerrimus* H. & A. | Ci | deerbrush, deerbrush ceanothus | SN, CR, SC |
| *C. jepsonii* Greene | Cj | muskbrush, Jepson ceanothus | 65 |
| *C. leucodermis* Greene *(C. divaricatus* Nutt.) | Cd | chaparral whitethorn | SC |
| *C. megacarpus* Nutt. | Cm | bigpod ceanothus | SC |
| *C. oliganthus* Nutt. | Co | hairy ceanothus | SC |
| *C. palmeri* Trel.[6] | Cpa | Palmer ceanothus | 156 |
| *C. papillosus* T. & G. | Cpl | wartleaf ceanothus | CR |
| *C. parryi* Trel. | Cpr | Parry ceanothus | 65 |
| *C. parvifolius* (Wats.) Trel. | Cpv | littleleaf ceanothus | 55 |
| *C. prostratus* Benth. | Cpo | squaw carpet | 37, 40 |
| *C. rigidus* Nutt. | Cri | Monterey ceanothus | 105C |
| *C. sorediatus* H. & A.[7] | Cso | Jimbrush | CR, SC |
| *C. spinosus* Nutt. | Csp | red-heart, greenbark ceanothus | SC |
| *C. thyrsiflorus* Esch. | Ct | blue blossom, bluebrush, wild lilac | CR |
| *C. tomentosus* Parry | Cto | woollyleaf ceanothus | 51, 192A |
| *C. velutinus* Dougl. | Cv | tobacco brush, snowbrush | 37, 54 |
| *C. verrucosus* Nutt. | Cve | wartystem ceanothus | 192A, D |
| *Cercis occidentalis* Torr. | Cec | California redbud, western redbud | 23 |
| *Cercocarpus betuloides* Nutt. | Cb | western mountain-mahogany, birchleaf mountain-mahogany | SN, CR, SC |
| *C. ledifolius* Nutt. | Cl | desert mountain-mahogany, curlleaf mountain-mahogany | 37 |
| *Chamaebatia foliolosa* Benth. | Cf | bearmat, mountain misery | SN |
| *Chrysothamnus* sp. | Chr | rabbitbrush | 54 |
| *C. nauseosus* (Pall.) Britton | Chn | rubber rabbitbrush | SN, SC |
| *C. viscidiflorus* (Hook.) Nutt. | Chv | rabbitbrush | 37, 155 |
| *Corethrogyne filaginifolia* (H. & A.) Nutt. | Cof | | 161A, B |
| *Cornus nuttallii* Aud. | Cn | Pacific dogwood | 38, 40 |
| *Cupressus forbesii* Jeps. | TY | Tecate cypress | 177 |
| *C. macrocarpa* Hartw. | MY | Monterey cypress | 105C |
| *C. sargentii* Jeps. | SY | Sargent cypress | 130C |
| *C. sargentii* Jeps. *(C. sargentii* var. *duttonii* Jeps.) | DY | | 81D |
| *Dendromecon rigida* Benth. | Dr | bush poppy | 156 |
| *Distichlis spicata* (L.) Greene | DIs | saltgrass | 161A |

Table 4—*Plant names and occurrence on profiles,* continued

| Scientific name | Symbol | Common name | Occurrence[1] |
|---|---|---|---|
| *Encelia californica* Nutt. | Enc | California encelia | SC |
| *E. farinosa* Gray | Enf | brittle-bush, desert encelia, incienso | 164C, 176 |
| *Ephedra viridis* Cov. | Epv | green ephedra | SC |
| *Eriodictyon californicum* (H. & A.) Torr. | Ec | California yerba santa | 78 |
| *E. crassifolium* Benth. | Ecr | thickleaf yerba santa | 192D |
| *Eriogonum cinerium* Benth. | Efc | ashyleaf buckwheat | 160D, 161C |
| *E. fasciculatum* Benth. | Ef | California buckwheat | CR, SC |
| *E. wrightii* Torr. | Ew | Wright buckwheat | 154 |
| *Erodium cicutarium* (L.) L' Hér.[4] | Eci | redstem filaree | CR, SC |
| *E. moschatum* (L.) L' Hér.[4] | Emo | whitestem filaree | 164B |
| *Eucalyptus* sp.[4] | Eu | | SC |
| *Festuca megalura* Nutt. | Fm | foxtail fescue | CR |
| *Fraxinus dipetala* H. & A. | Fd | flowering ash, two-petal ash | SN, CR |
| *Fremontodendron californicum* Cov. | Fc | California fremontia, flannel bush | 164A |
| *Garrya flavescens* Wats. | Gfl | pale silktassel | 85A |
| *G. fremontii* Torr. | Gf | Fremont silktassel | SN, CR |
| *G. veatchii* Kell. | Gv | Veatch silktassel | 155, 156 |
| *Gutierrezia sarothrae* (Pursh) Britt. & Rusby | Gsa | broom snakeweed | 154, 163B |
| *Haplopappus bloomeri* Gray *(Chrysothamnus bloomeri* Greene) | Chb | Bloomer goldenbush | 55 |
| *H. ericoides* (Less.) H. & A. *(Ericameria ericoides* Jeps.) | Ee | heather goldenbush | 157 |
| *H. linearifolius* DC. *(Stenotopsis linearifolia* Rydb.) | Sli | narrowleaf goldenbush | CR, SC |
| *H. palmeri* Gray *(Ericameria palmeri* Hall) | Epa | Palmer goldenbush | 161A |
| *H. pinifolius* Gray *(Ericameria pinifolia* Hall) | Epi | pine goldenbush | 161B |
| *Helianthus gracilentus* Gray | Hgr | slender sunflower | 161C |
| *Heteromeles arbutifolia* M. Roem. *(Photinia arbutifolia* Lindl.) | Pa | Christmasberry, toyon | SN, CR, SC |
| *Holodiscus discolor* (Pursh) Maxim. | Hd | cream bush, ocean spray | 84 |
| *Hordeum* sp. | Hm | barley | CR |
| *Hymenoclea salsola* T. & G. | Hys | white burrobrush | SC |
| *Juglans californica* Wats. | WC | California walnut | SC |
| *Juniperus californica* Carr. | Jc | California juniper | CR, SC |
| *J. occidentalis* Hook. | Jo | western juniper | 37, 77 |
| *J. osteosperma* (Torr.) Little *(J. utahensis* Lemmon) | Ju | Utah juniper | 54 |

Table 4—*Plant names and occurrence on profiles,* continued

| Scientific name | Symbol | Common name | Occurrence[1] |
|---|---|---|---|
| *Larrea tridentata* Sessé & Moçiño | Lt | creosote bush | 164A, B |
| *Lepidospartum squamatum* (Gray) Gray | Lsq | scalebroom | SC |
| *Leptodactylon pungens* (Torr.) Rydb. | Lpu | granite-gilia | 55, 155 |
| *Libocedrus decurrens* Torr. | I | incense-cedar | SN, SC |
| *Lithocarpus densiflorus* (H. & A.) Rehd. | T | tanoak, tanbark-oak | SN, CR |
| *L. densiflorus* (shrub form) | Ld | | 106B, 131B |
| *L. densiflorus* var. *echinoides* (R. Br.) Abrams | Lde | dwarf tanoak | 23, 38 |
| *Lonicera subspicata* var. *johnstonii* Keck | Lsu | southern honeysuckle | 130D |
| *Lotus scoparius* (Nutt.) Ottley | Ls | deerweed | CR, SC |
| *Lupinus* sp. | Lpx | lupine | 55, 154 |
| *L. albifrons* Benth. | La | silver lupine | 160D |
| *Medicago polymorpha* L. *(M. hispida* Gaertn.)[4] | Mhi | bur-clover | CR |
| *Nicotiana glauca* Grah.[4] | Ng | tree tobacco | SC |
| *Opuntia* sp. | Ox | prickly-pear, cholla | 164C |
| *Penstemon antirrhinoides* Benth. | Pan | yellow penstemon | 176 |
| *Pickeringia montana* Nutt. | Pm | chaparral-pea | CR |
| *Pinus albicaulis* Engelm. | WP | whitebark pine | 54, 55 |
| *P. attenuata* Lemmon | K | knobcone pine | SN, CR |
| *P. contorta* Dougl. | L | lodgepole pine | SN |
| *P. coulteri* D. Don | CP | Coulter pine | CR, SC |
| *P. flexilis* James | LP | limber pine | 155 |
| *P. jeffreyi* Grev. & Balf. | J | Jeffrey pine | SN, SC |
| *P. lambertiana* Dougl. | S | sugar pine | SN, CR, SC |
| *P. monophylla* Torr. & Frém. | P | singleleaf pinyon | SN, SC |
| *P. monticola* Dougl. | W' | western white pine | SN |
| *P. muricata* D. Don | BP | bishop pine | 157 |
| *P. ponderosa* Lawson | Y | ponderosa pine, yellow pine | SN, CR, SC |
| *P. radiata* D. Don | MP | Monterey pine | 84, 105C |
| *P. sabiniana* Dougl. | DP | Digger pine | SN, CR, SC |
| *P. torreyana* Parry | TP | Torrey pine | 192A |
| *Platanus racemosa* Nutt. | S | California sycamore | SN, CR, SC |
| *Pluchea sericea* (Nutt.) Cov. | Pse | arrowweed | 156 |
| *Populus fremontii* Wats. | F | Fremont cottonwood | SN, CR, SC |
| *P. tremuloides* Michx. | A | quaking aspen | 37, 77 |
| *P. trichocarpa* T. & G. | B | black cottonwood | SN, SC |
| *Prunus emarginata* Dougl. | Pe | bitter cherry | SN |
| *P. fasciculata* (Torr.) Gray | Pf | desert almond | 164A |
| *P. ilicifolia* (Nutt.) D. Dietr. | Pi | hollyleaf cherry, islay | SC |
| *Pseudotsuga macrocarpa* (Vasey) Mayr | BS | bigcone Douglas-fir, bigcone spruce | SC |

Table 4—*Plant names and occurrence on profiles,* continued

| Scientific name | Symbol | Common name | Occurrence[1] |
|---|---|---|---|
| *P. menziesii* (Mirb.) Franco | D | Douglas-fir | SN, CR |
| *Pteridium aquilinum* var. *pubescens* Underwood | Pta | bracken | SN, CR, SC |
| *Purshia glandulosa* Curran | Pg | desert bitterbrush | 164A |
| *P. tridentata* (Pursh) DC. | Pt | antelope bitterbrush | 54 |
| *Quercus agrifolia* Née | A | coast live oak, California live oak | CR, SC |
| *Q. agrifolia* (shrub form) | Qa | | 157 |
| *Q. Xalvordiana* Eastw.[8] | QD | | 130D, 133B |
| *Q. chrysolepis* Liebm. | C | canyon live oak | SN, CR, SC |
| *Q. chrysolepis* (shrub form) | Qc | | CR, SC |
| *Q. douglasii* H. & A. | D' | blue oak | SN, CR |
| *Q. dumosa* Nutt. | Qd | California scrub oak | SN, CR, SC |
| *Q. durata* Jeps. | Qdu | leather oak | CR |
| *Q. engelmannii* Greene | E | Engelmann oak | SC |
| *Q. garryana* var. *breweri* (Engelm.) Jeps. | Qgb | Brewer oak | 23, 40 |
| *Q. garryana* var. *semota* Jeps. | Qgs | Kaweah white oak | 154 |
| *Q. kelloggii* Newb. | B | California black oak | SN, CR, SC |
| *Q. kelloggii* (shrub form) | Qk | | 23 |
| *Q. lobata* Née | V | California white oak, valley oak | SN, CR, SC |
| *Q. vaccinifolia* Kell. | Qv | huckleberry oak | SN |
| *Q. wislizenii* A. DC. | W | interior live oak | SN, CR, SC |
| *Q. wislizenii* (shrub form) | Qw | | SN, CR, SC |
| *Rhamnus californica* Esch. | Rc | California coffeeberry, California buckthorn | CR, SC |
| *R. crocea* var. *ilicifolia* (Kell.) Greene | Rci | hollyleaf redberry, hollyleaf buckthorn | SN, CR |
| *Rhus diversiloba* T. & G. | Rd | poison-oak | SN, CR, SC |
| *R. integrifolia* (Nutt.) Benth. & Hook. | Ri | lemonadeberry, lemonade sumac | SC |
| *R. laurina* Nutt. | Rl | laurel sumac | SC |
| *Salicornia virginica* L. *(S. ambigua* Michx.) | Saa | glasswort, pickleweed | 192A |
| *Salix* sp. | Sx | willow | SN, CR, SC |
| *Salsola pestifera* A. Nels. *(S. kali* var. *tenuifolia* Tausch.)[4] | Skt | Russian-thistle | 54, 161A |
| *Salvia apiana* Jeps. | Sa | white sage | SC |
| *S. dorrii* (Kell.) Abrams *(S. carnosa* Dougl.) | Scr | desert sage | SC |
| *S. leucophylla* Greene | Sl | purple sage | SC |
| *S. mellifera* Greene | Sm | black sage | CR, SC |

Table 4—*Plant names and occurrence on profiles,* continued

| Scientific name | Symbol | Common name | Occurrence[1] |
|---|---|---|---|
| *Sambucus caerulea* Raf. *(S. glauca* Nutt.) | Sg | blue elderberry | 161B, 177 |
| *Scirpus acutus* Muhl. | Sca | common tule | 49E |
| *Sequoia gigantea* (Lindl.) Dcne. | BT | giant sequoia, big-tree | 69, 77 |
| *S. sempervirens* (D. Don) Endl. | R | redwood | CR |
| *Styrax officinalis* var. *californica* (Torr.) Rehd. | So | snowdrop bush | 23 |
| *Tetradymia canescens* DC. | Tc | gray horsebrush | 37, 54 |
| *Tsuga mertensiana* (Bong.) Carr. | HM, Hm | mountain hemlock | SN |
| *Umbellularia californica* (H. & A.) Nutt. | L' | California-laurel, California-bay | CR, SC |
| *U. californica* (shrub form) | Uc | | SN, CR |
| *Vaccinium ovatum* Pursh | Vo | California huckleberry | 84 |
| *Wyethia mollis* Gray | Wm | | 37, 52 |
| *Xylococcus bicolor* Nutt. *(Arctostaphylos bicolor* Gray) | Ab | Mission manzanita | SC |
| *Yucca brevifolia* Engelm. | YB | Joshua-tree | SC |
| *Y. schidigera* Roezl *(Y. mohavensis* Sarg.) | Ym | Mohave yucca, Spanish dagger | 164A |
| *Y. whipplei* Torr. | Yw | quixote plant, Our Lord's candle, chaparral yucca | SC |

[1]Profile numbers are listed if plant is represented on only one or two profiles. The geographic occurrence of plants on three or more profiles is indicated by these symbols: SN (Sierra Nevada: profiles 33-56, 69-78), CR (Coast Ranges: profiles 65 and 81-133), and SC (Southern California: profiles 153-192).

[2]The manzanita designated Acn on profiles 106A, 107C, and 131B is now considered part of the *A. glandulosa* complex.

[3]The manzanita designated At on profiles 130C to 191 is now considered part of the *A. glandulosa* complex. This is also true of all but the low-elevation occurrences near the coast on profiles 84, 85C, and 106B.

[4]Introduced.

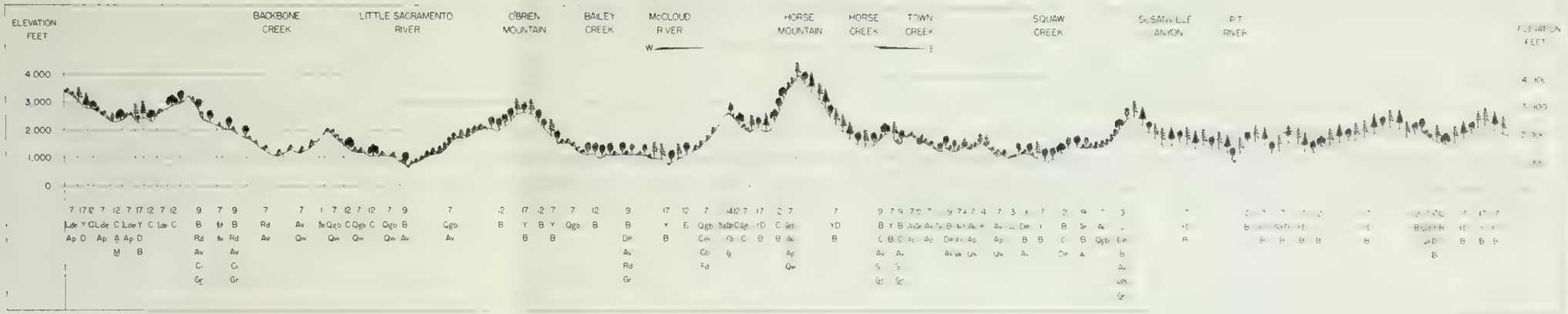
[5]Typical *C. dentatus* occurs only near the coast, according to McMinn (1942). The ceanothus designated Cde on profile 133B is probably *C. foliosus* var. *medius* McMinn, thought to be closely related to *C. dentatus* (McMinn 1942, p. 223).

[6]McMinn (1942, p. 187) identified this ceanothus of Santa Barbara and Ventura Counties as *C. integerrimus,* but noted that it is "undoubtedly very closely related to *C. palmeri.*"

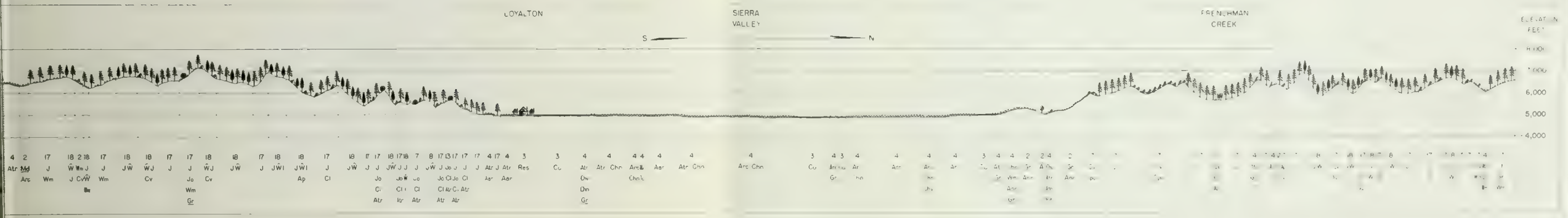
[7]The ceanothus identified as Cso on profile 191 is probably the closely related *C. oliganthus.*

[8]Typed as the tree form of *Q. dumosa,* but now considered a mixture of *Q. turbinella* and hybrid derivatives of *Q. douglasii* and *Q. turbinella.*

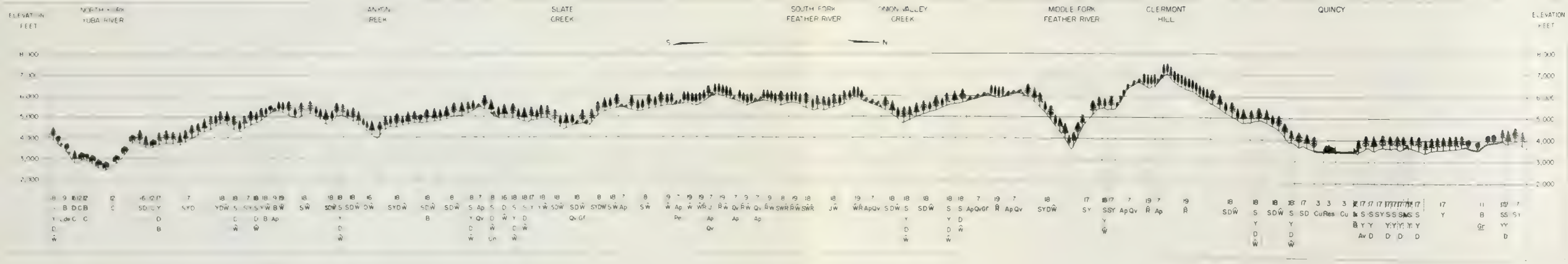
23 Redding




37 Sierraville

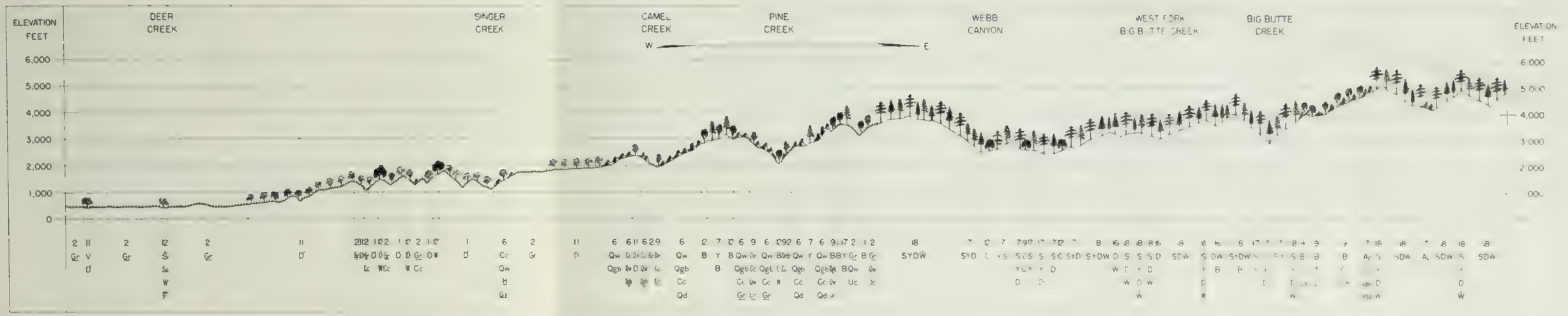


## 38 Downieville




## 39 Bidwell Bar

40 Chico

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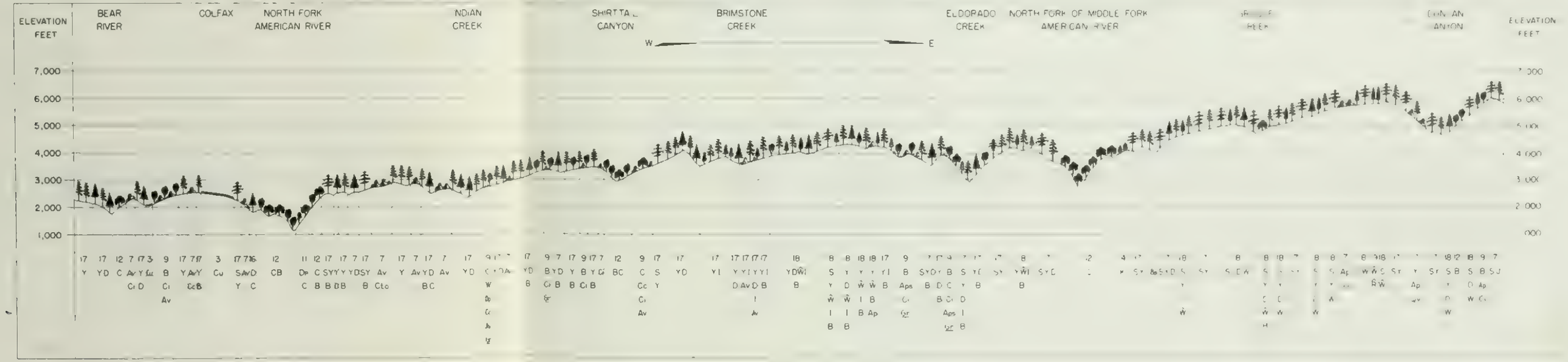
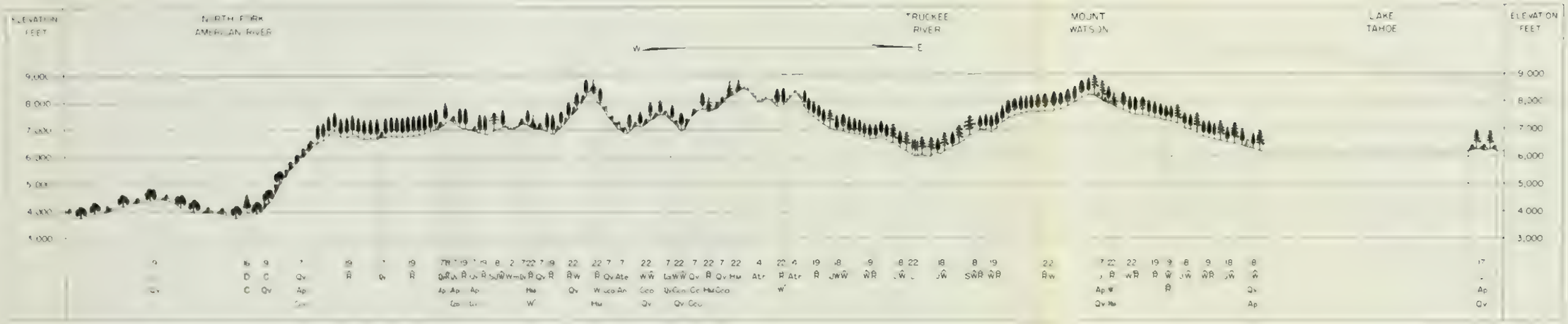


## 52 Truckee

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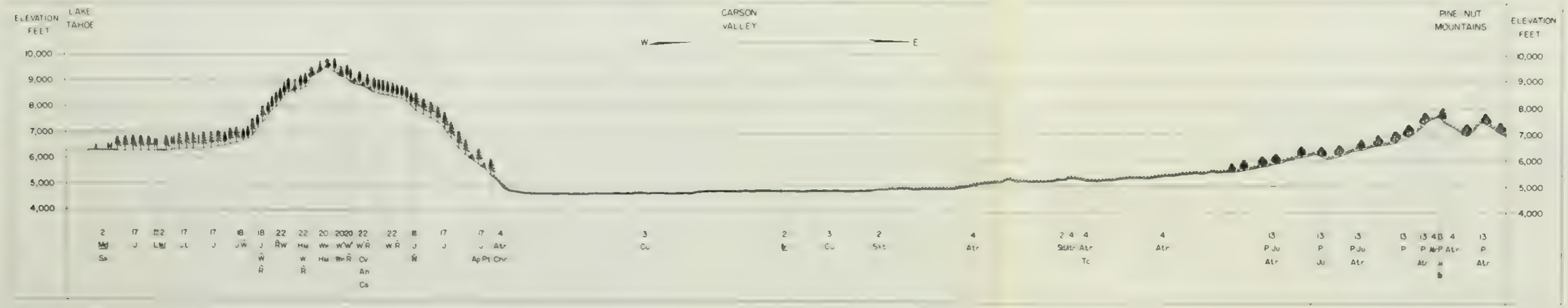
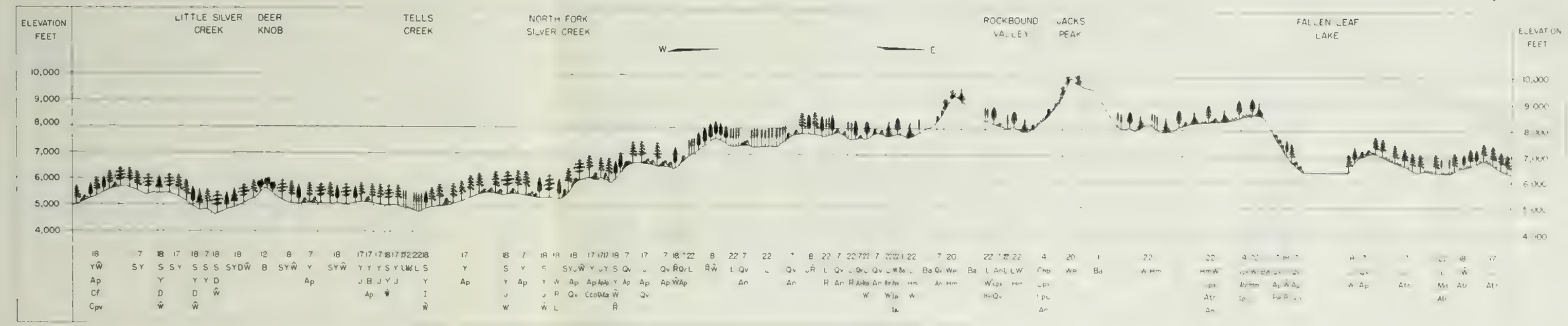
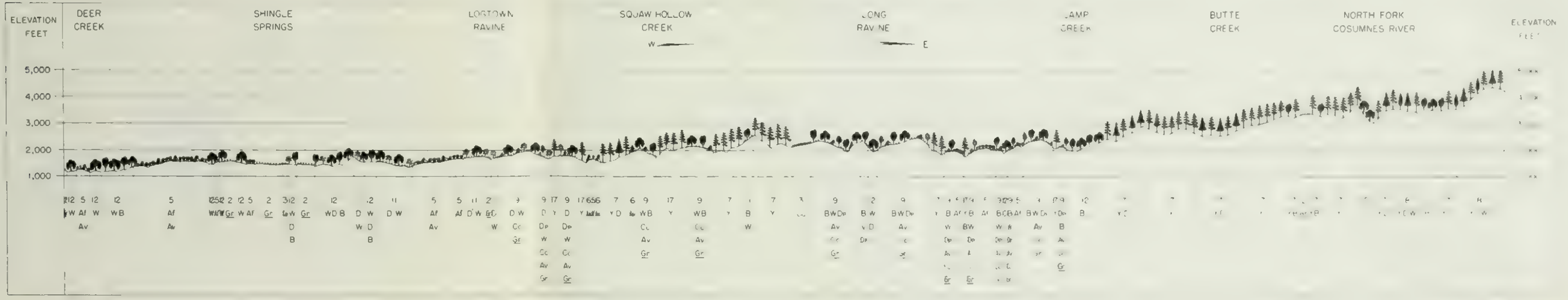


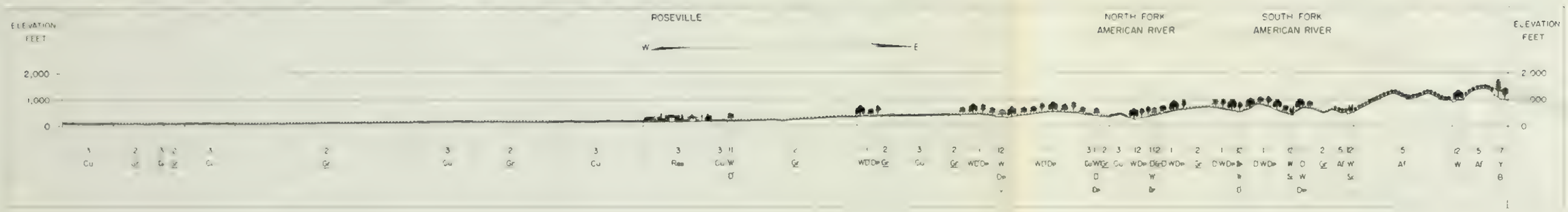
55 Pyramid Peak



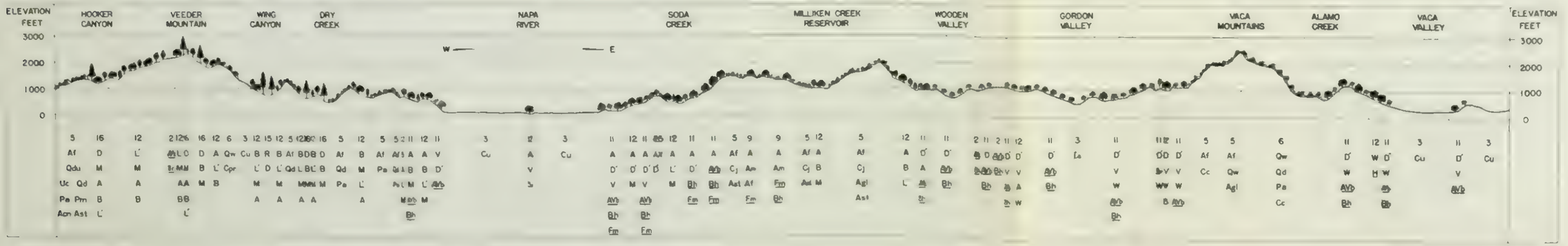

56 Placerville

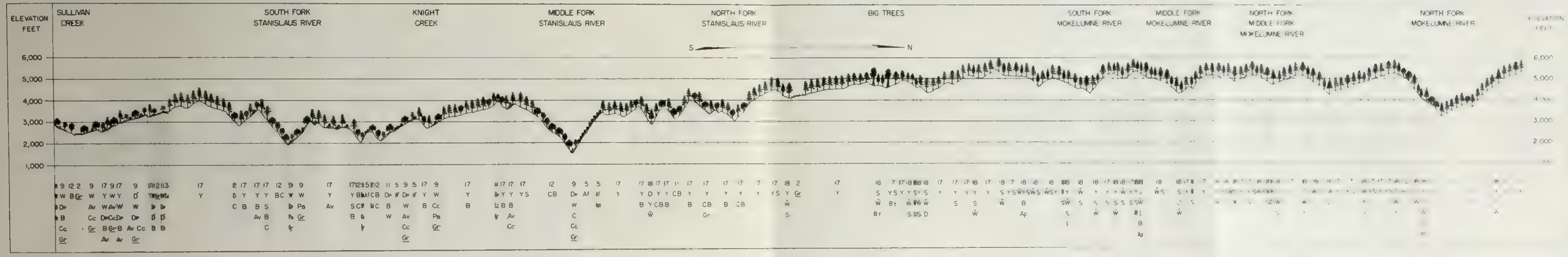


57 Sacramento




65 Napa

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SOUTH FORK STANISLAUS RIVER
KNIGHT CREEK
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NORTH FORK STANISLAUS RIVER
BIG TREES
SOUTH FORK MOKELUMNE RIVER
MIDDLE FORK MOKELUMNE RIVER
NORTH FORK MIDDLE FORK MOKELUMNE RIVER
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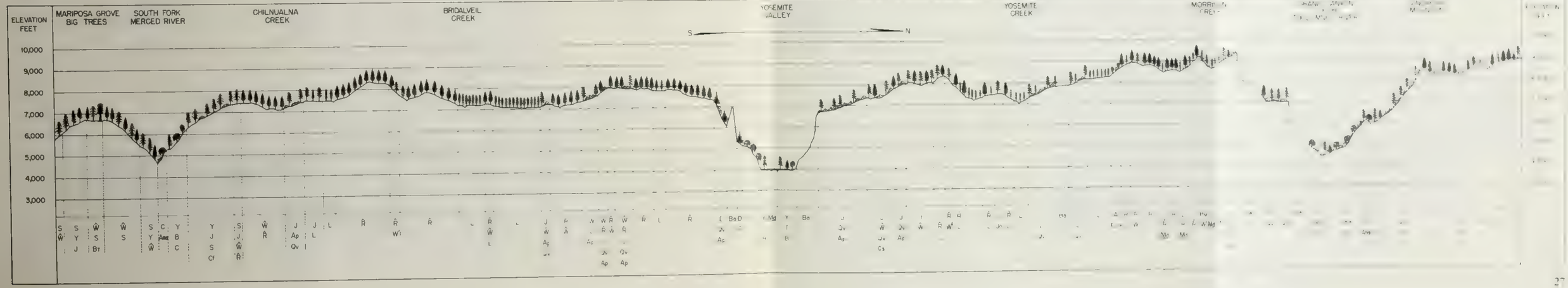
ELEVATION FEET
MARIPOSA GROVE BIG TREES
SOUTH FORK MERCED RIVER
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BRIDALVEIL CREEK
YOSEMITE VALLEY
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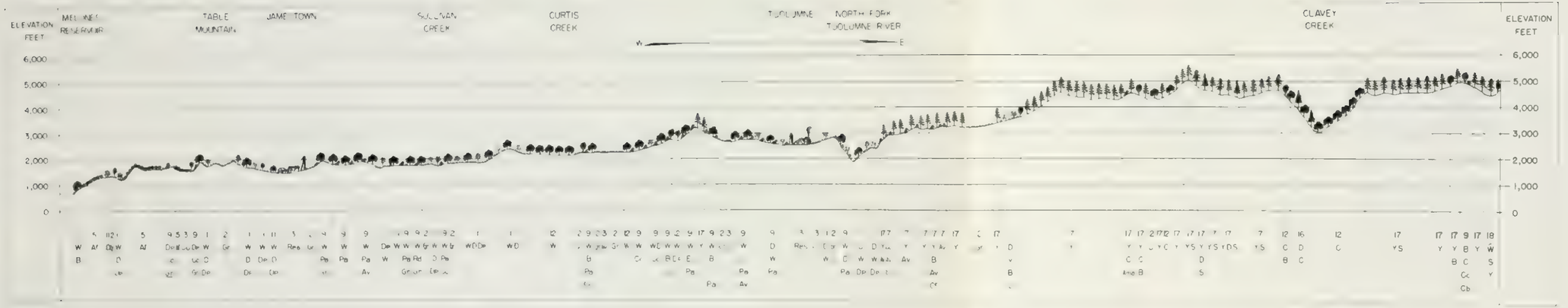
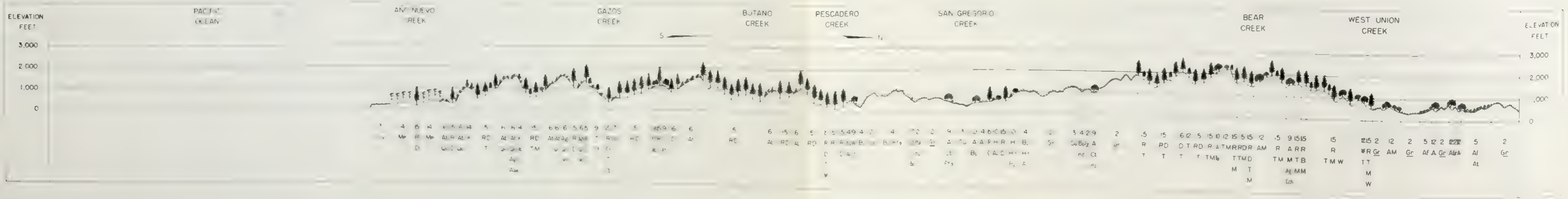
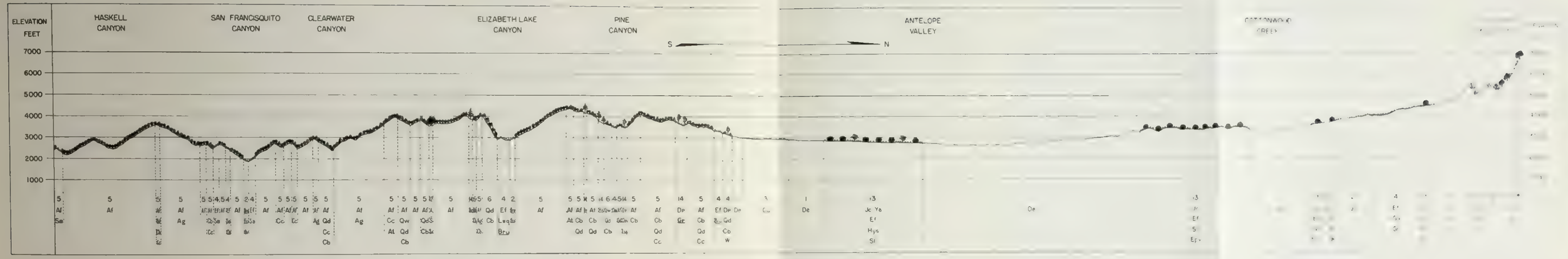
78 Sonora



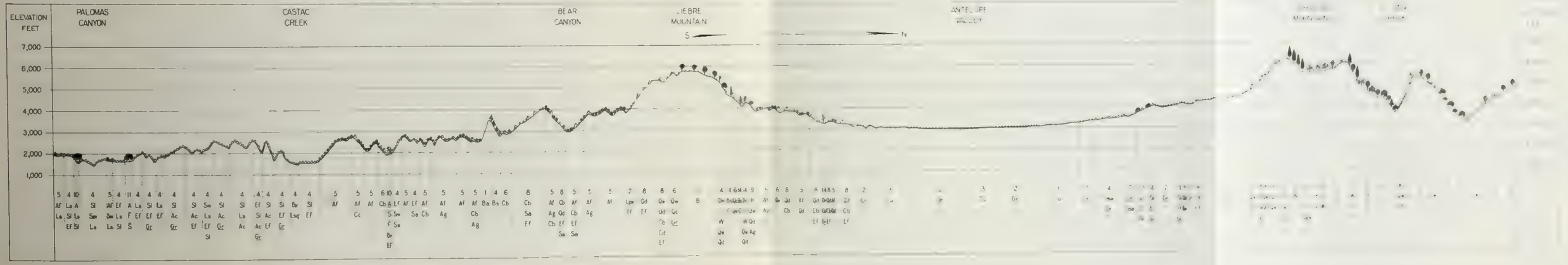

84 Santa Cruz



153 Elizabeth Lake




154 Tejon



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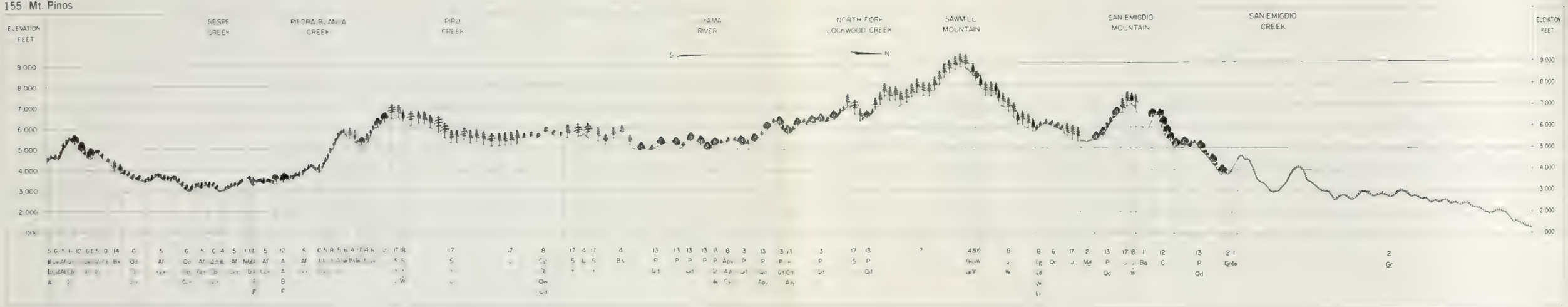
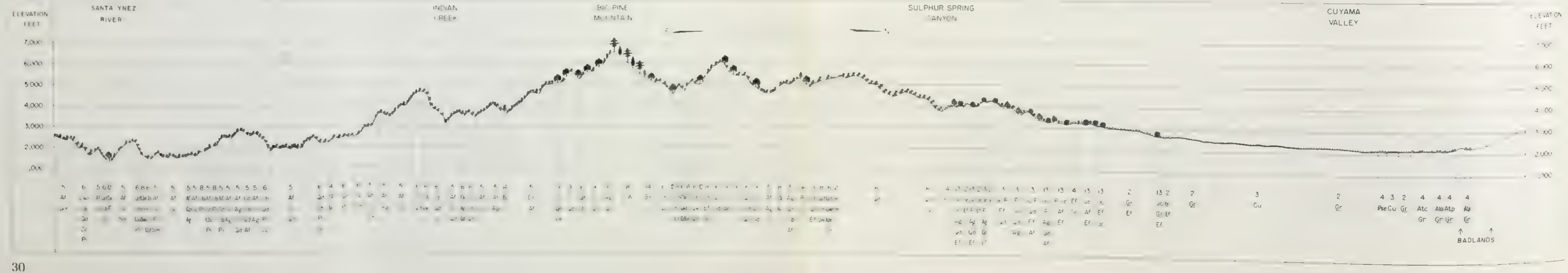
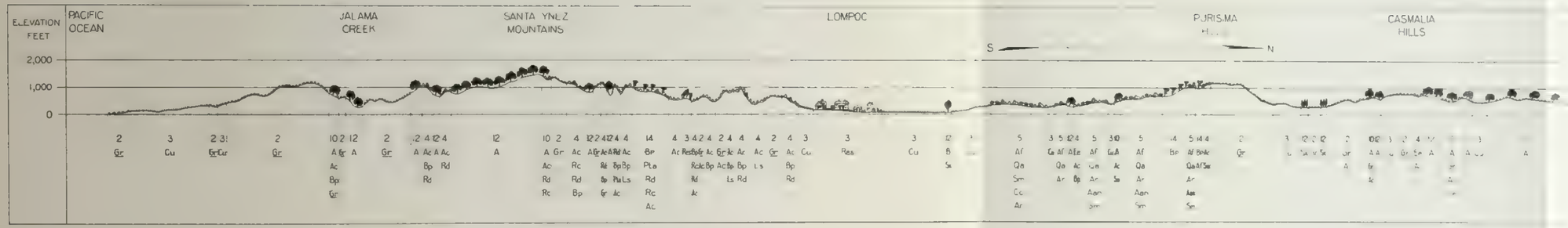
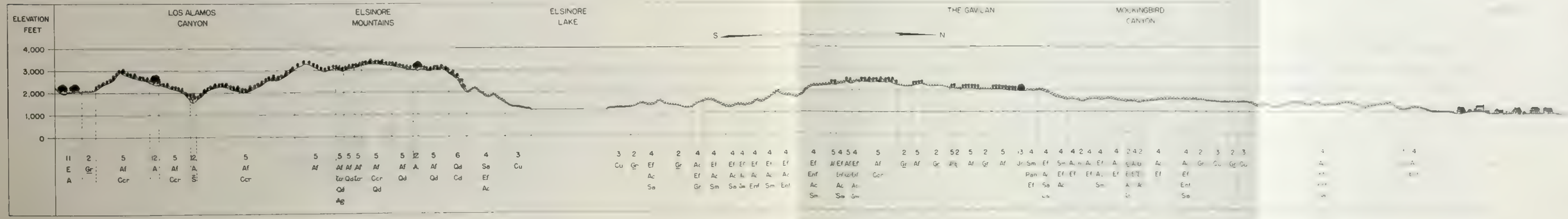



156 Santa Ynez




ELEVATION FEET
PACIFIC OCEAN
JALAMA CREEK
SANTA YNEZ MOUNTAINS
LOMPOC
PURISMA H...
CASMALIA HILLS
S
N
2,000
1,000
0


ELEVATION FEET
LOS ALAMOS CANYON
ELSINORE MOUNTAINS
ELSINORE LAKE
THE GAVILAN
MOCKINGBIRD CANYON
S
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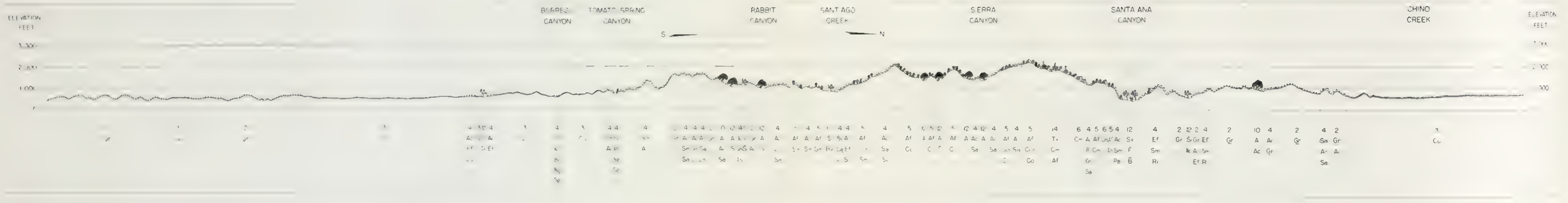
4,000
3,000
2,000
1,000
0

177 Corona

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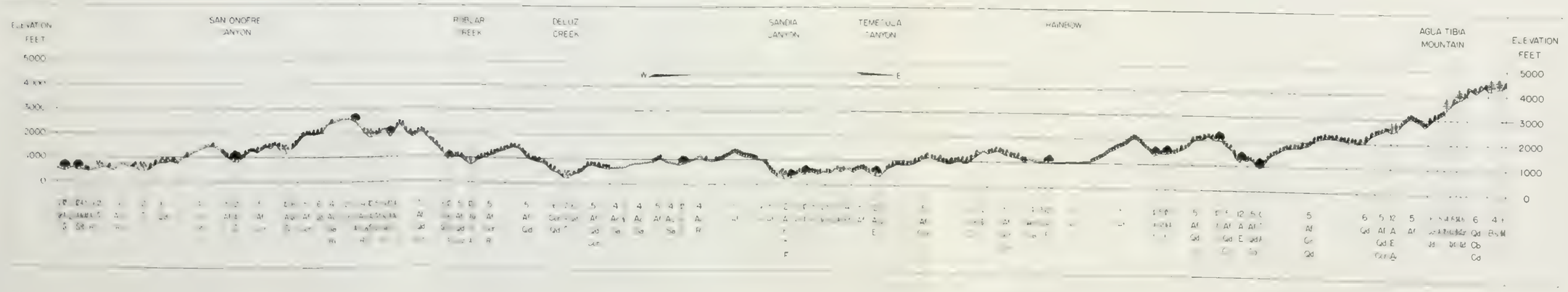
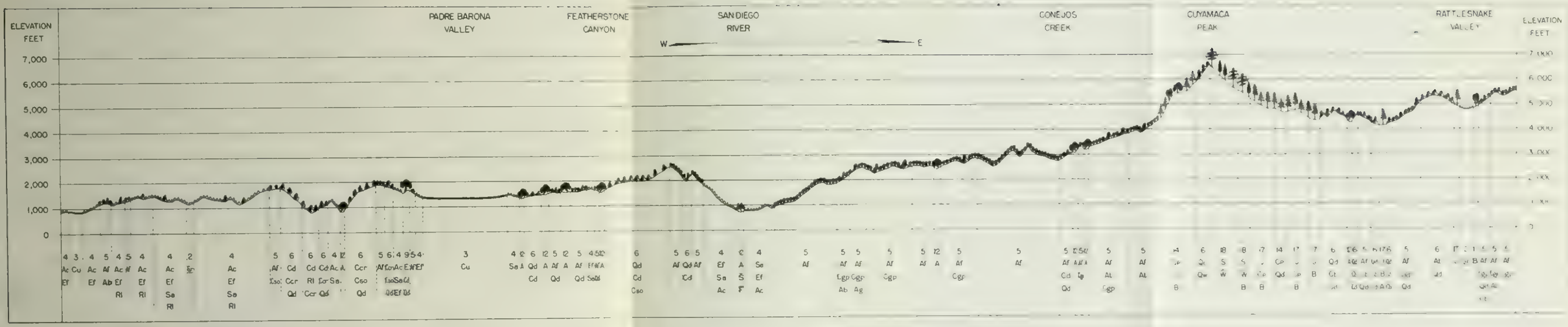
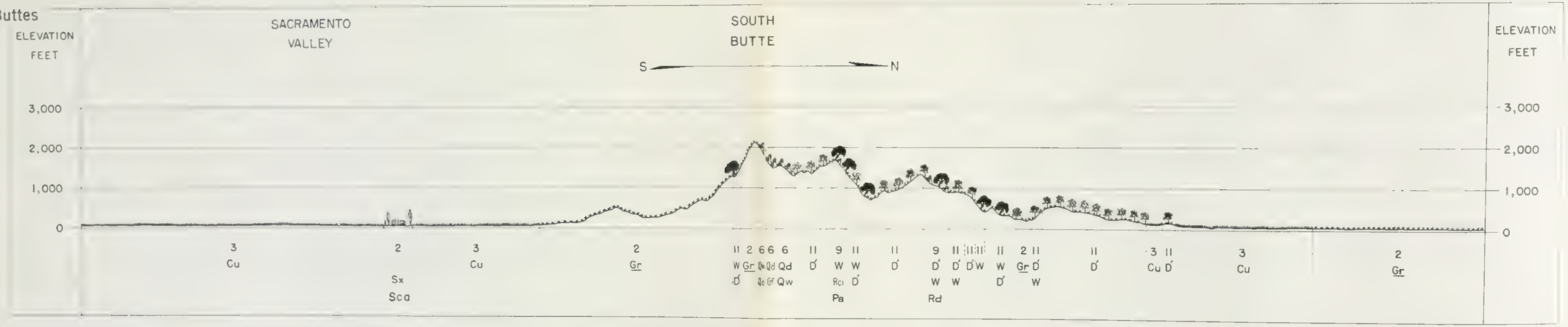
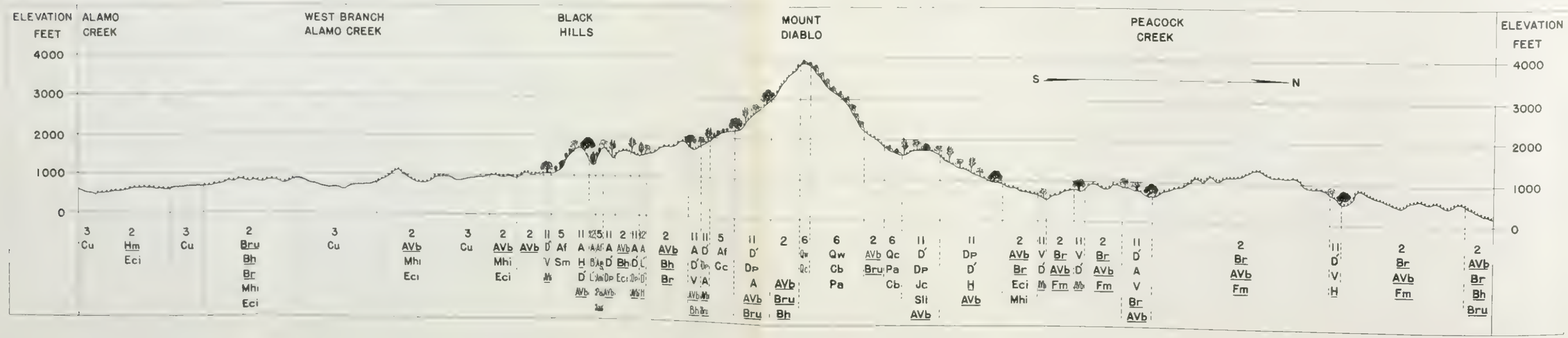



ELEVATION FEET
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
PADRE BARONA VALLEY
FEATHERSTONE CANYON
SAN DIEGO RIVER
W
E
CONEJOS CREEK
CUYAMACA PEAK
RATTLESNAKE VALLEY
ELEVATION FEET

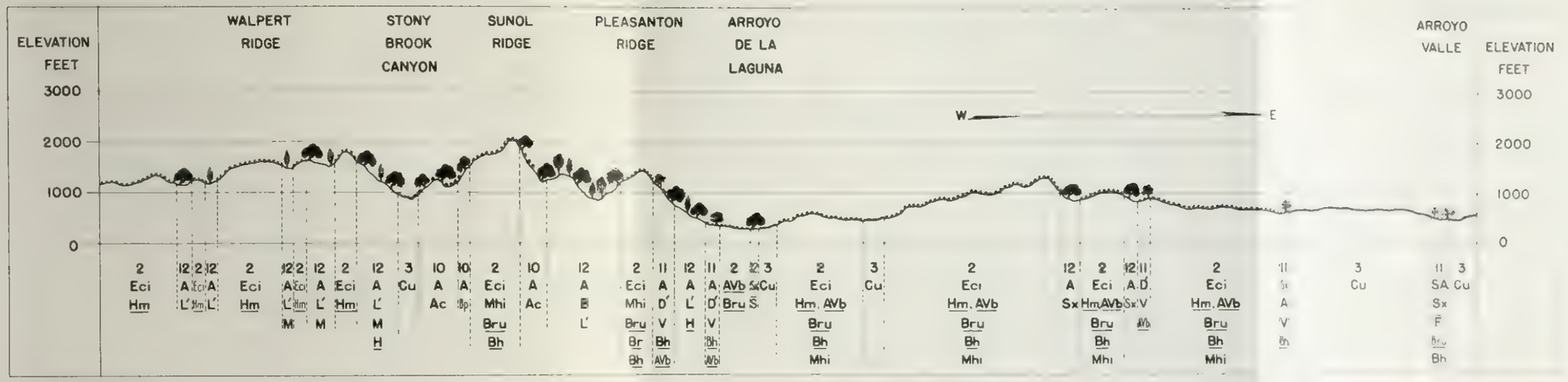
49E Marysville Buttes



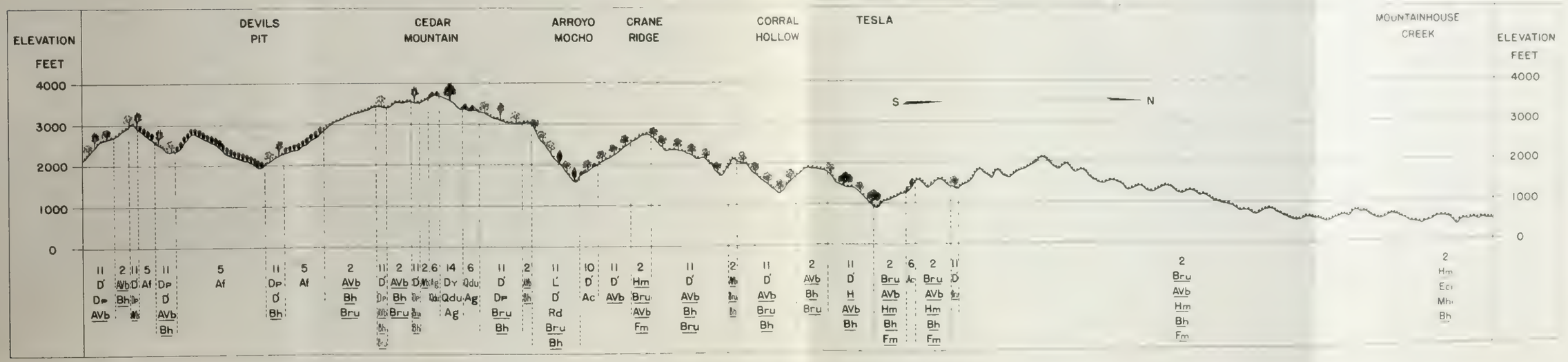

81B Mt. Diablo



81C Pleasanton




81D Tesla



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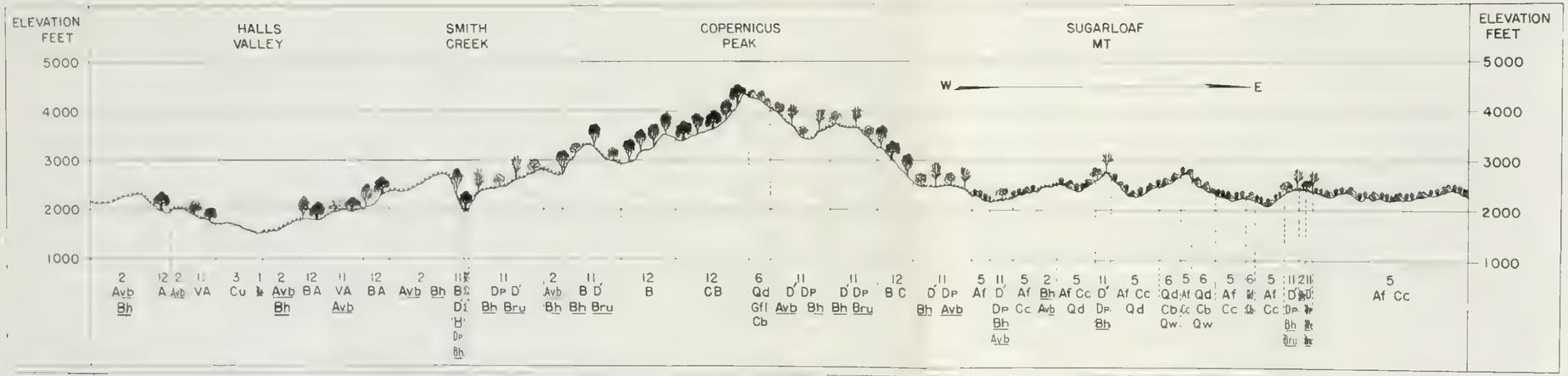


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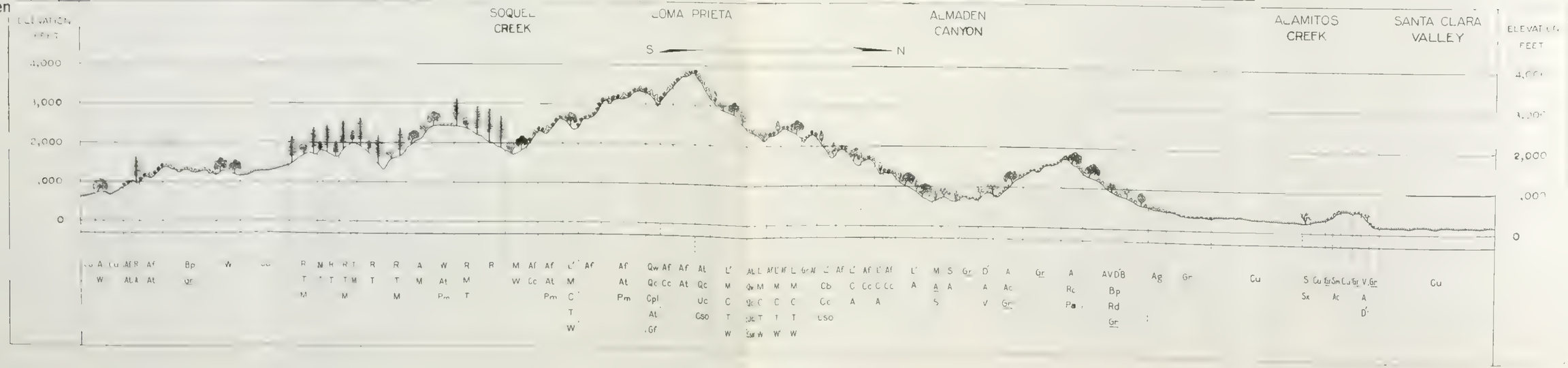
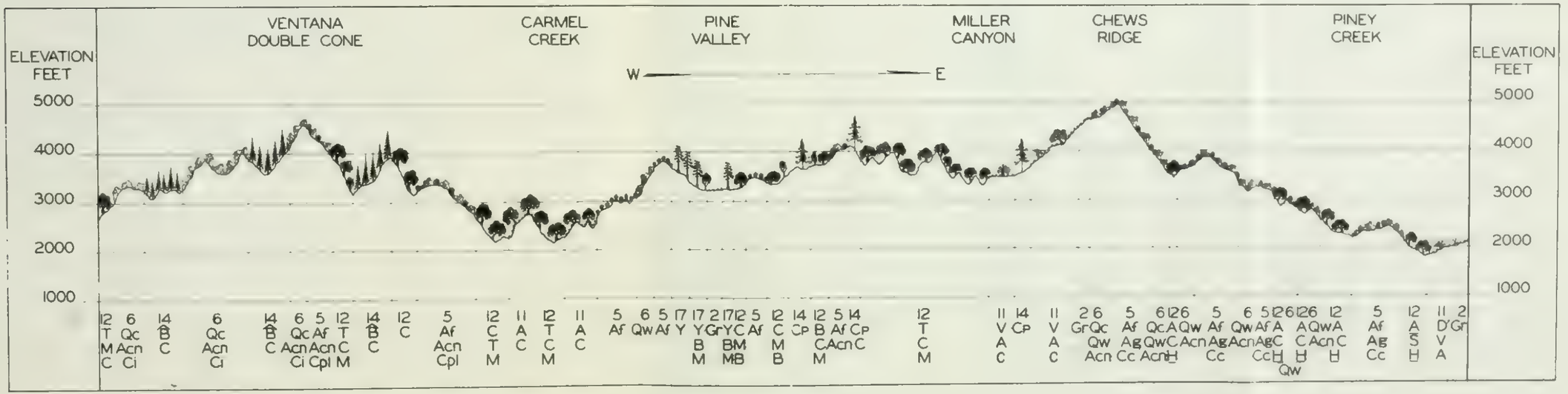
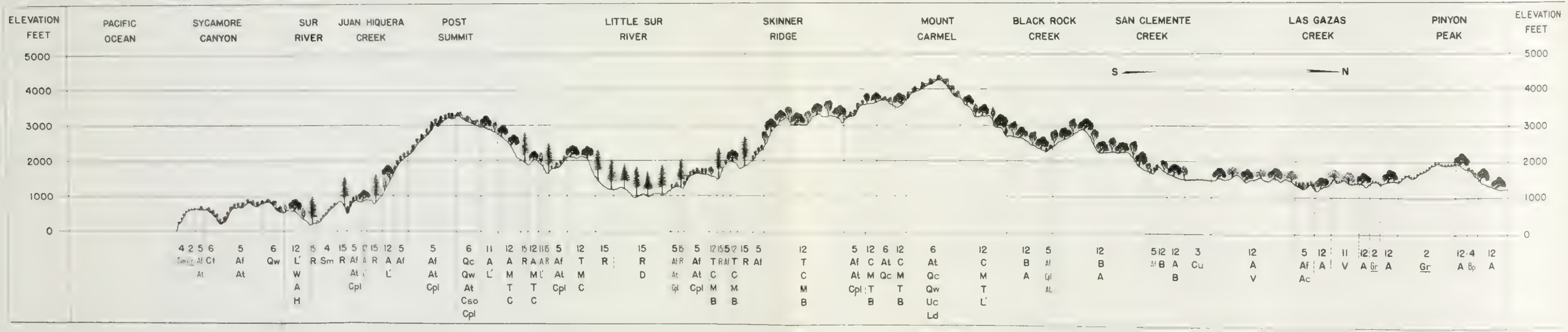


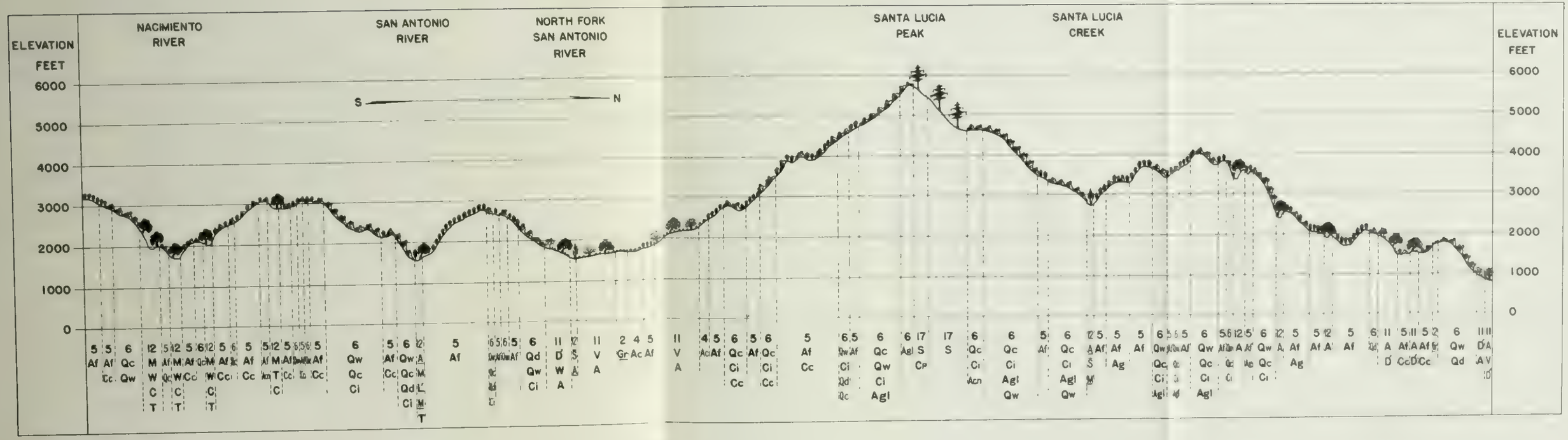
105C Monterey



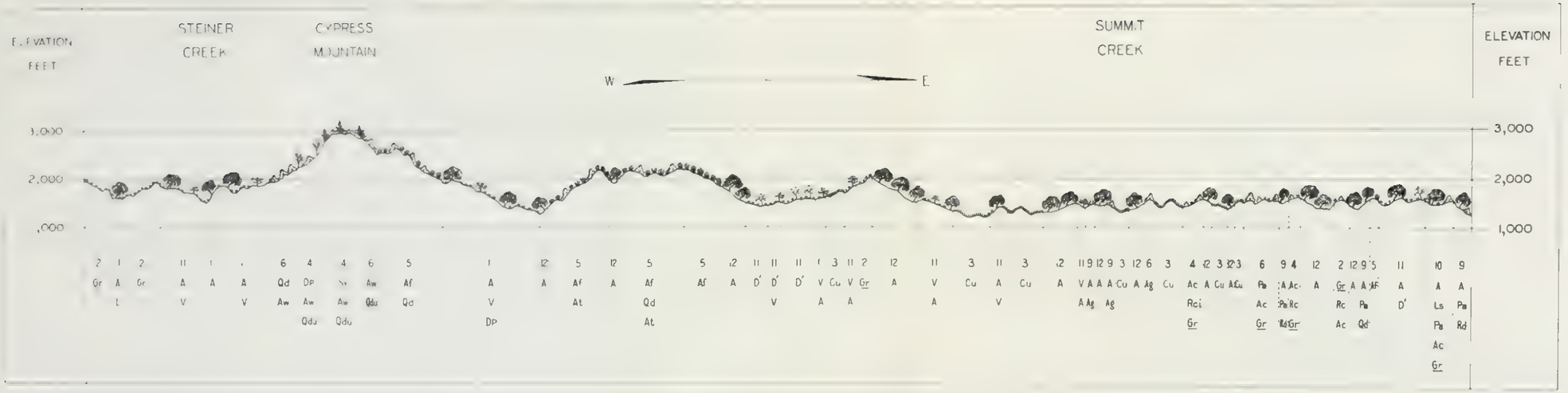

106A Jamesburg

## 106B Point Sur

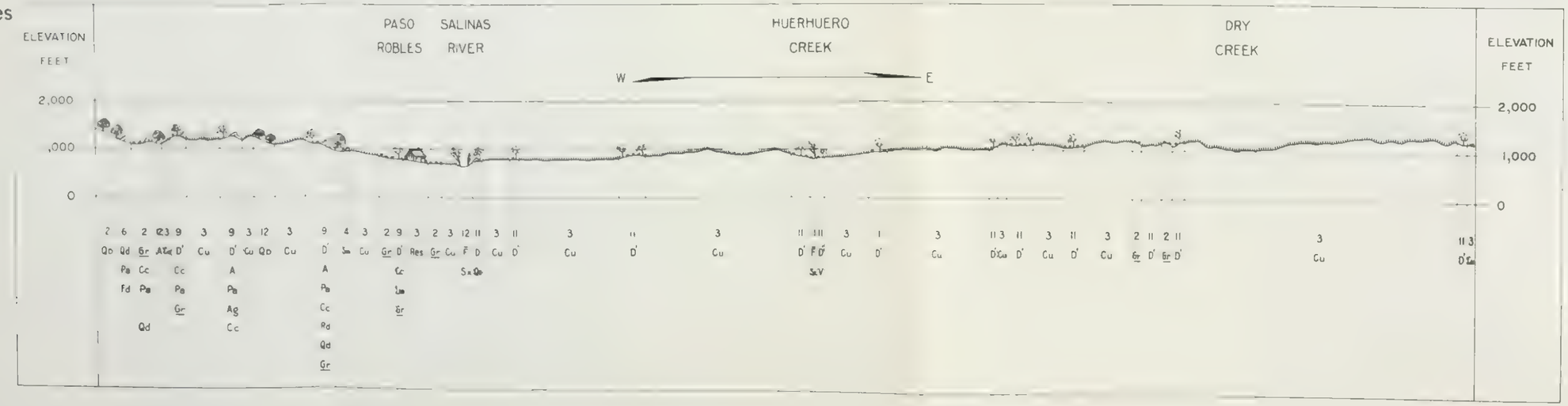


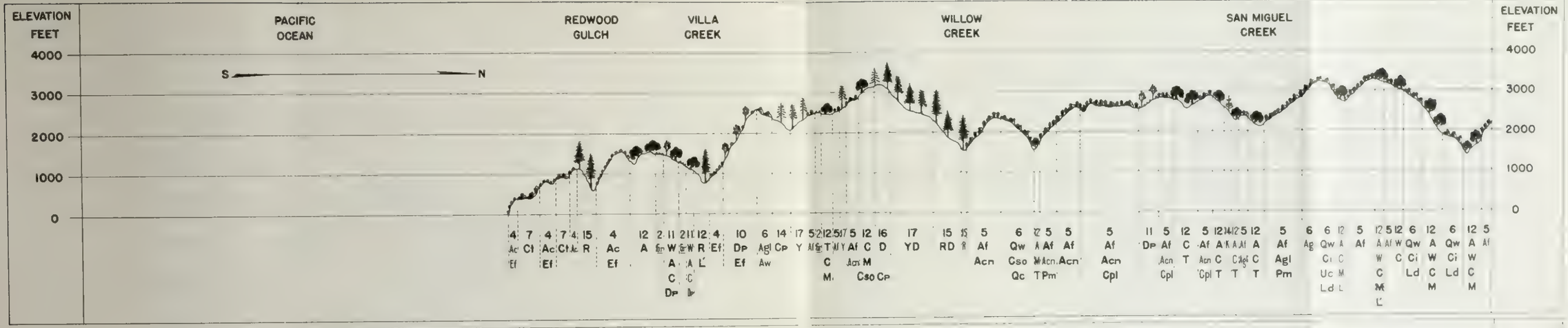

ELEVATION FEET
6000
5000
4000
3000
2000
1000
0
NACIMIENTO RIVER
SAN ANTONIO RIVER
NORTH FORK SAN ANTONIO RIVER
SANTA LUCIA PEAK
SANTA LUCIA CREEK
S
N
ELEVATION FEET
6000
5000
4000
3000
2000
1000
0

## 130C Adelaida




## 130D Paso Robles



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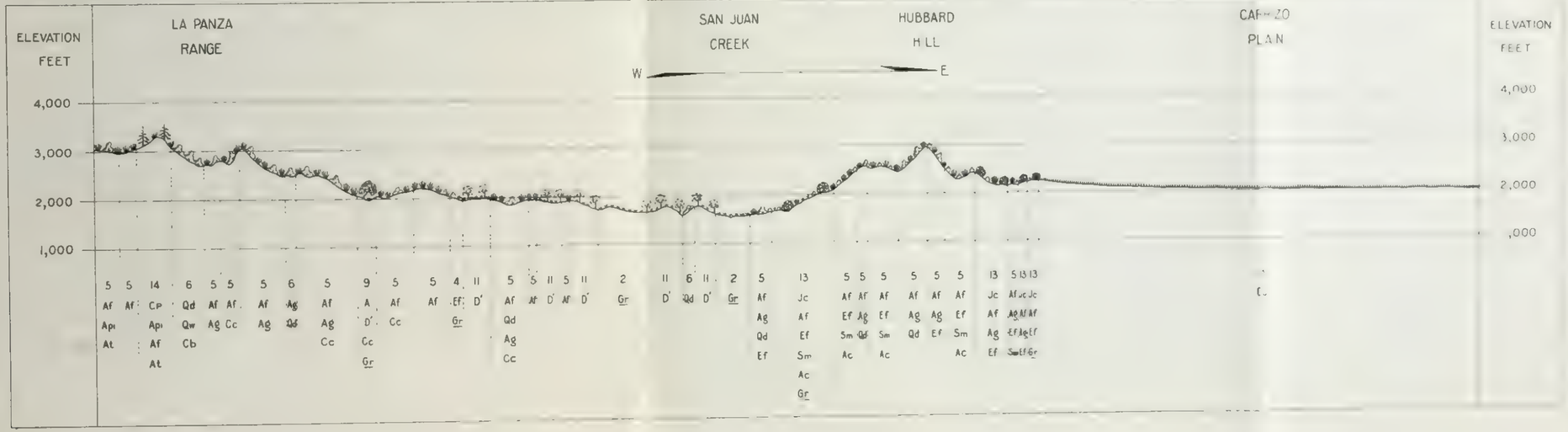
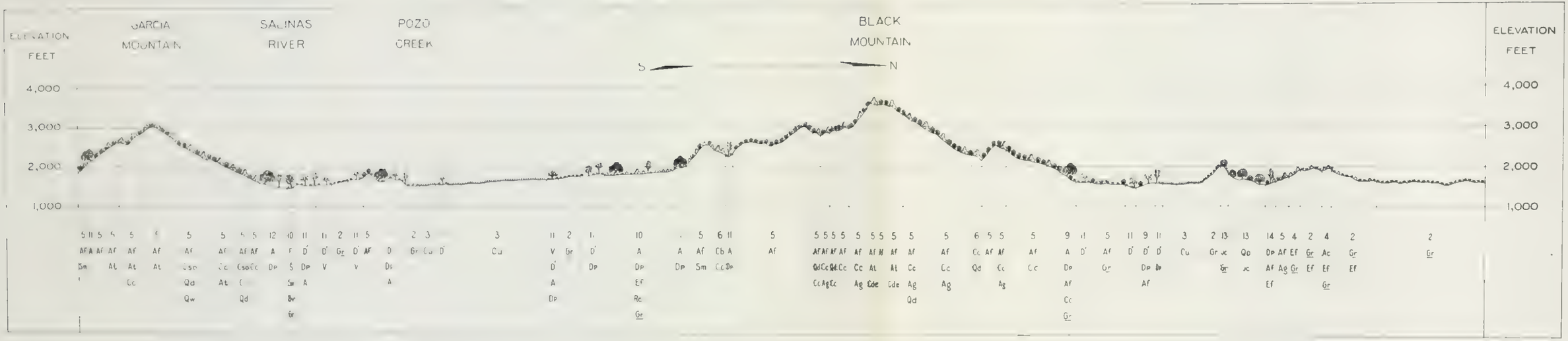
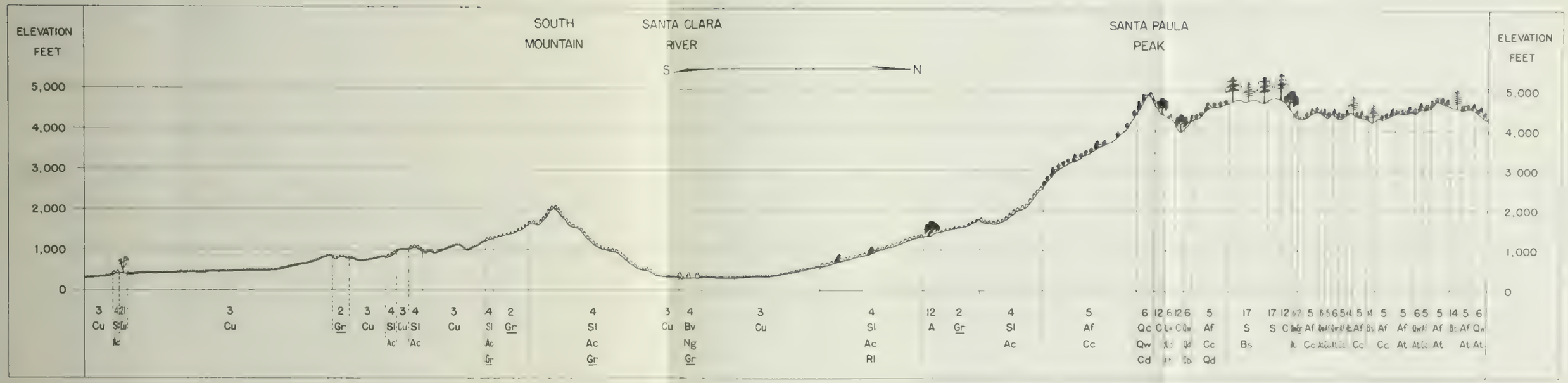


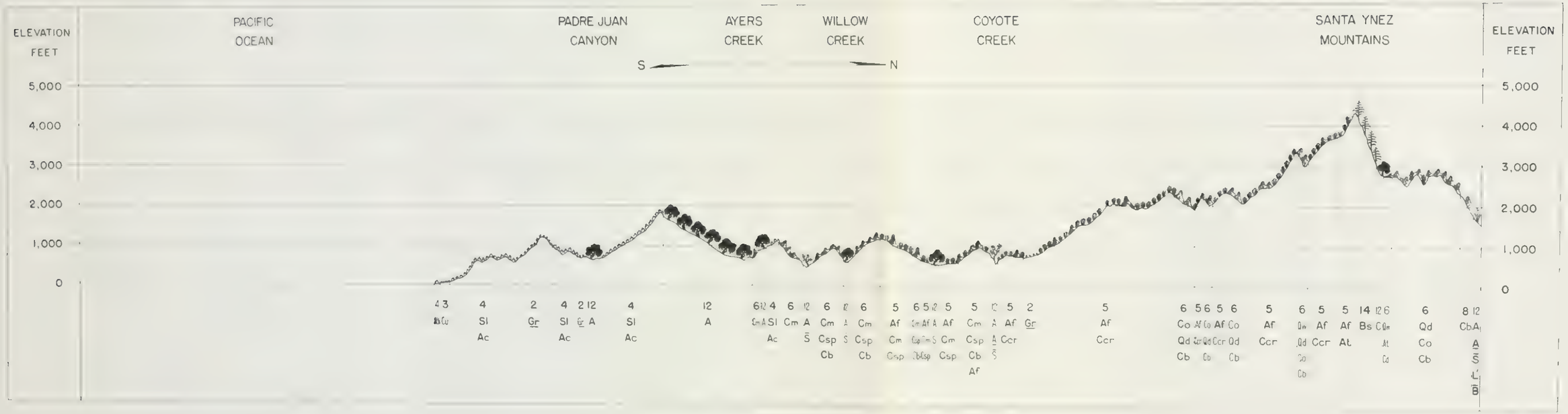

133A La Panza

## 133B Pozo

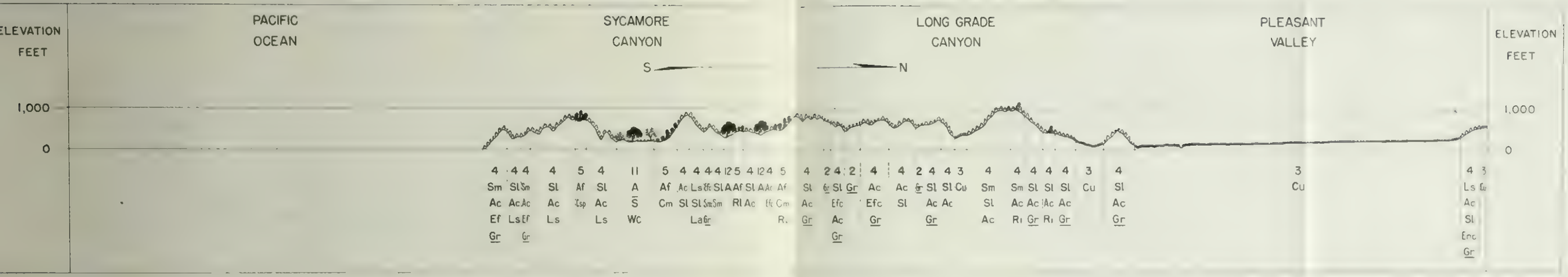

ELEVATION
FEET
GARCIA
MOUNTAIN
SALINAS
RIVER
POZO
CREEK
BLACK
MOUNTAIN
S
N
4,000
3,000
2,000
1,000
ELEVATION
FEET


ELEVATION
FEET
5,000
4,000
3,000
2,000
1,000
0
SOUTH
MOUNTAIN
SANTA CLARA
RIVER
S
N
SANTA PAULA
PEAK
ELEVATION
FEET
5,000
4,000
3,000
2,000
1,000
0

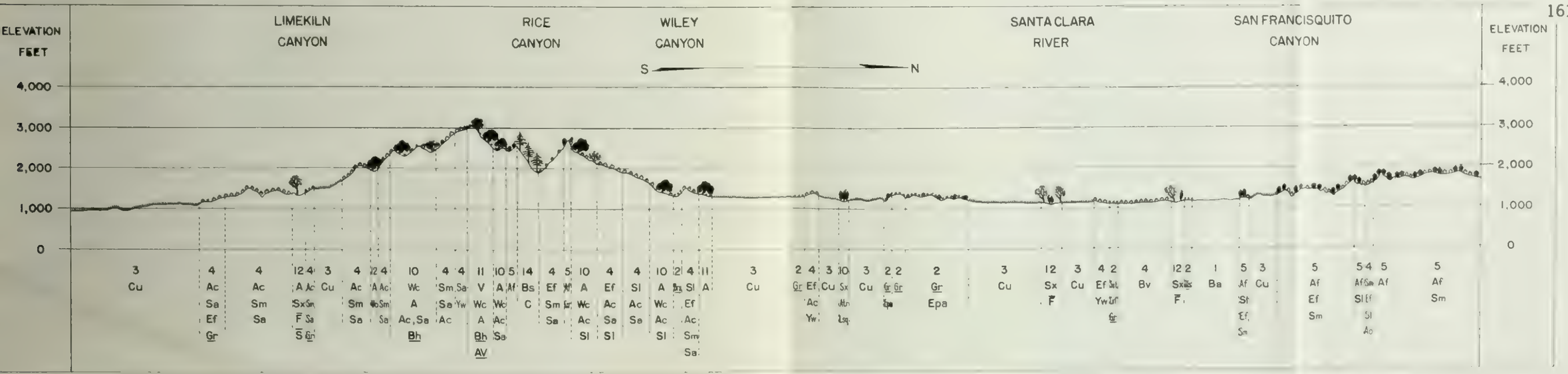
160B Ventura



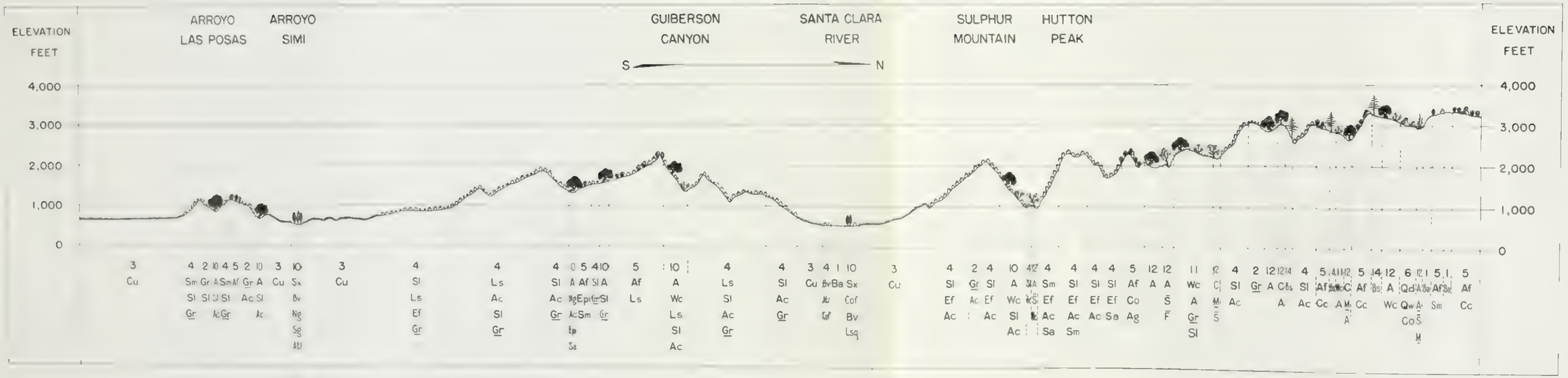
160D Hueneme

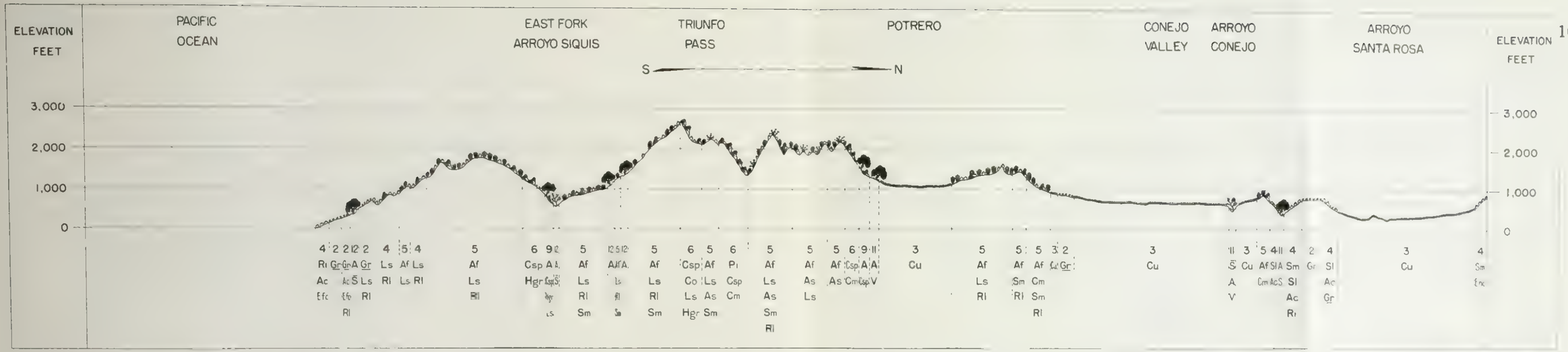



161A Santa Susana

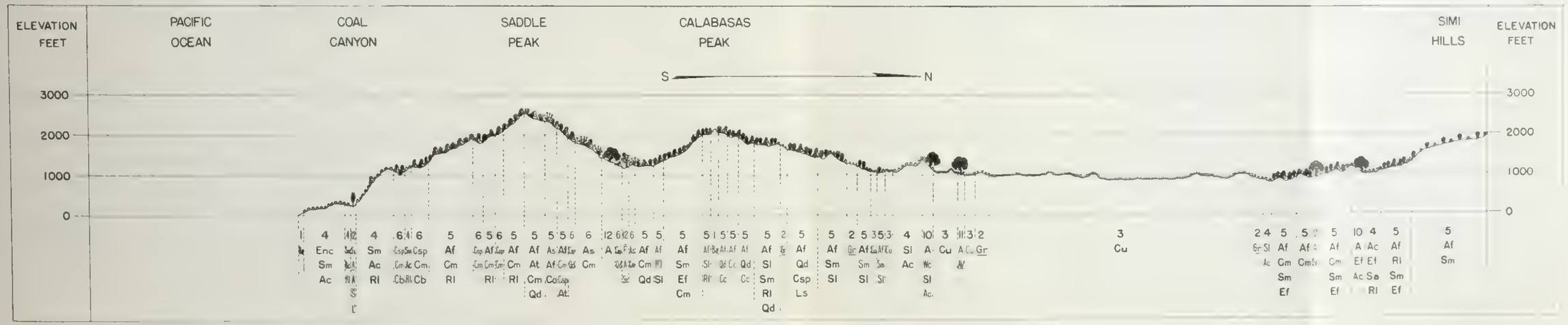


## 161B Piru


ELEVATION FEET
ARROYO LAS POSAS
ARROYO SIMI
GUIBERSON CANYON
SANTA CLARA RIVER
SULPHUR MOUNTAIN
HUTTON PEAK
S
N
4,000
3,000
2,000
1,000
0

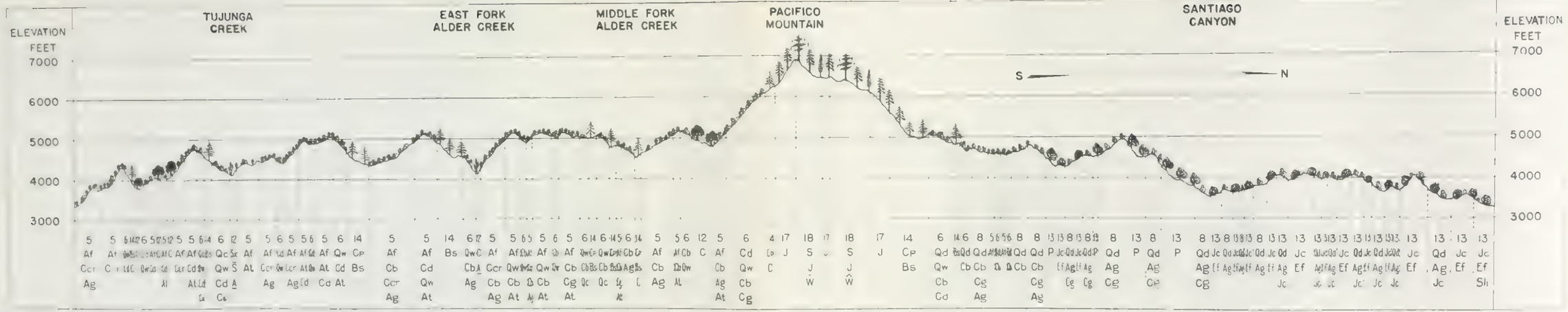



161C Triunfo Pass

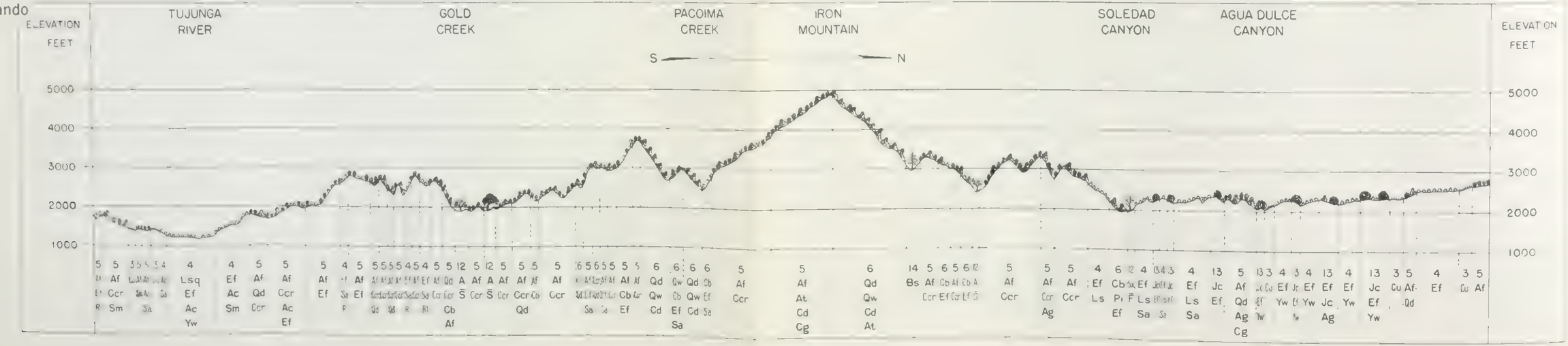



161D Calabasas

## 162A Tujunga




## 162B San Fernando



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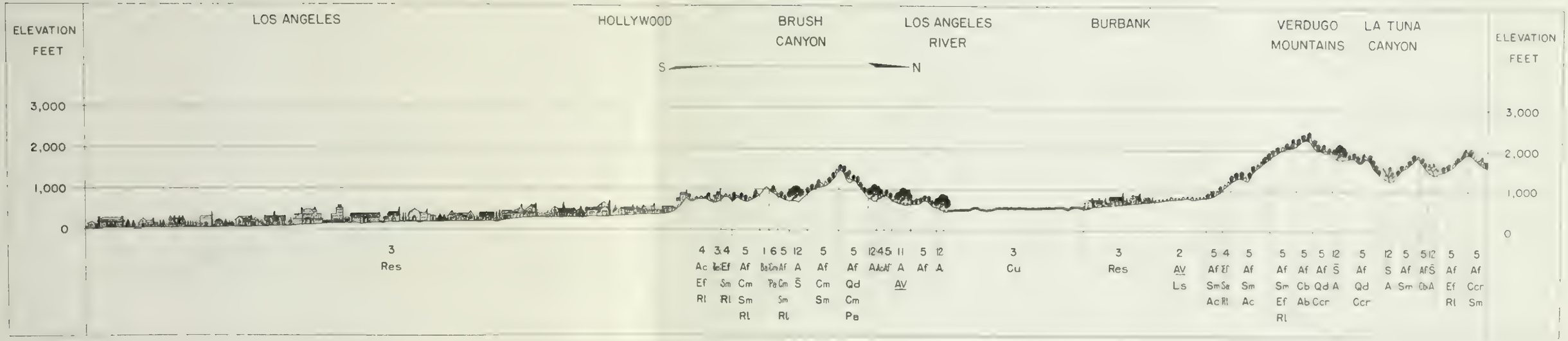
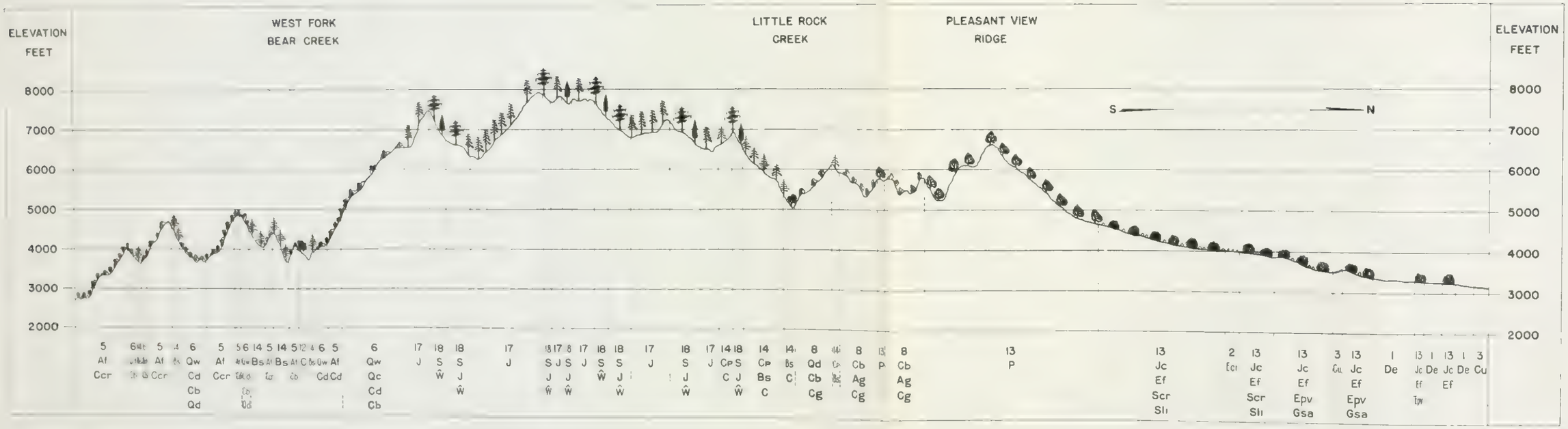
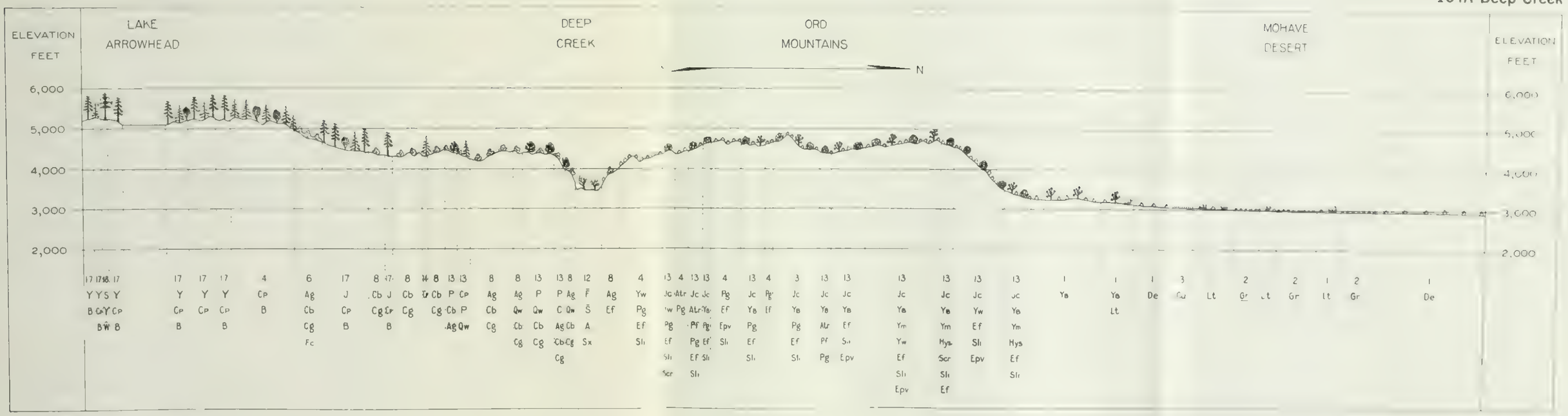


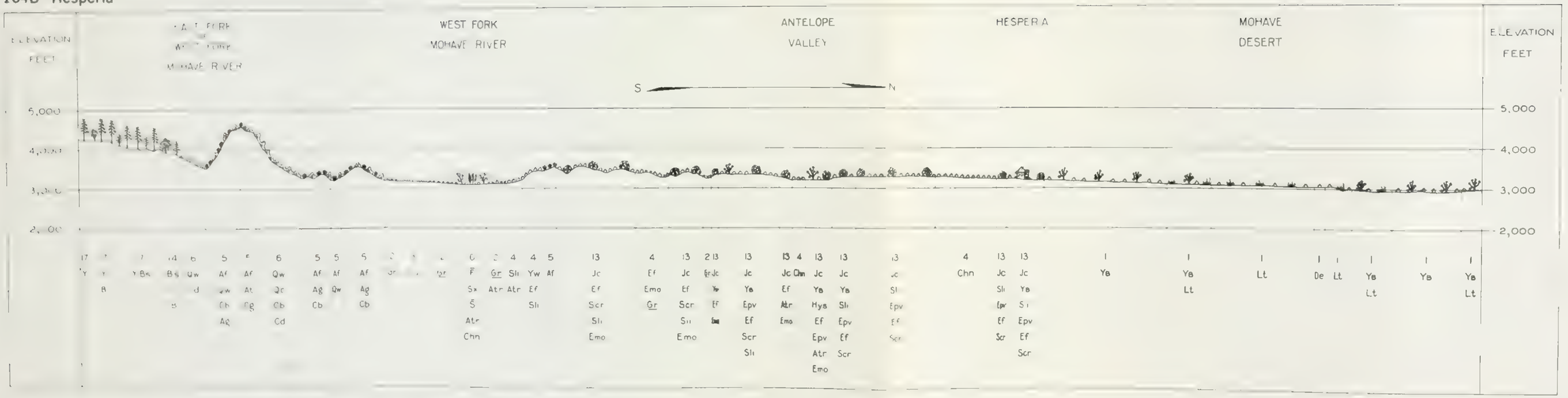
## 163B Rock Creek

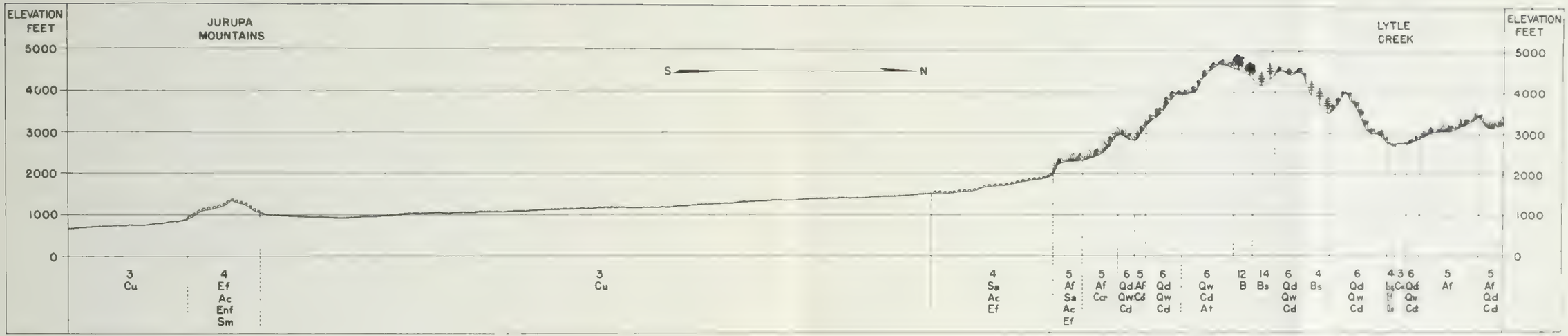


## 164A Deep Creek

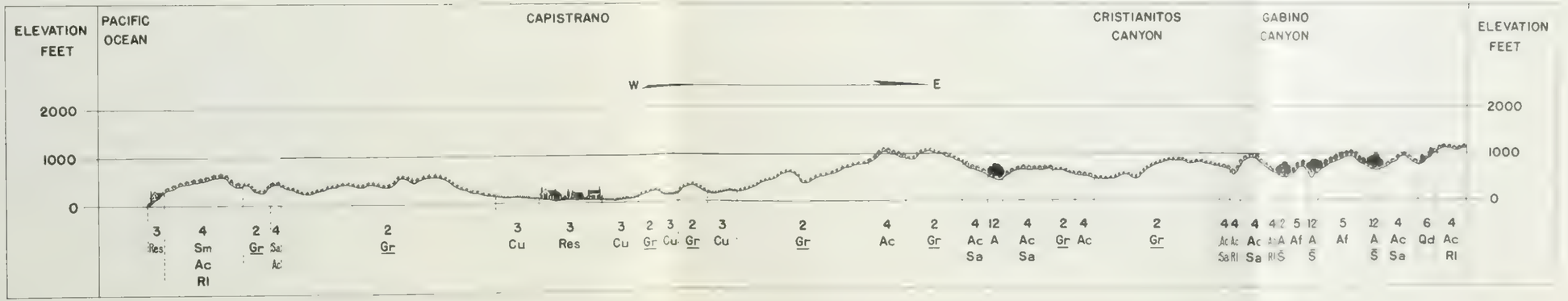


## 164B Hesperia






164C San Bernardino




179A Capistrano

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SERVICE
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X 245, BERKELEY, CALIFORNIA 94701

# REST-ROTATION GRAZING AT HARVEY VALLEY...

## range health, cattle gains, costs

Raymond D. Ratliff  Jack N. Reppert  Richard J. McConnen

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## The Authors

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## ACKNOWLEDGMENTS

Many people have had a hand in the research on rest-rotation grazing at Harvey Valley.

Special credit is due *A. L. (Gus) Hormay,* formerly of the Pacific Southwest Forest and Range Experiment Station and now with the U.S. Bureau of Land Management, who headed research at Harvey Valley until 1961; *E. J. (Joe) Wolfolk,* formerly Assistant Director for range and wildlife habitat research at the Station, who gave valued guidance and direction to our efforts; *Roney Brothers,* the Harvey Valley permittee whose cooperation made it possible to collect data and apply rest and grazing treatments; members of the *Lassen National Forest* staff—particularly Philip B. Lord, Fred J. Alberico, and Bill Sanderson—and of the Forest Service's *California Region*; *Donald W. Seegrist,* formerly of the Experiment Station staff and now with the Northeastern Forest Experiment Station, who guided the data analyses; and *Beecher Crampton,* University of California, Davis, who helped with plant identification.

We also thank the permittees of the Gray's Valley and Lower Pine Creek allotments—*Irene Jefcoat* and *Julian Mapes*—who contributed to the livestock studies; *Les Williams,* U.S. Soil Conservation Service; and the following members of the Experiment Station staff: *Merton J. Reed, C. Eugene Conrad, Donald L. Neal, James L. Mallory, Stanley E. Westfall,* and *Lynn O. Hylton.*

Credit for completing the task of collecting data goes to the technicians and student aids of the Experiment Station.

One objective of U.S. Forest Service range management is to provide economic stability to livestock operations and rural communities that depend upon rangelands for support. Mountain rangelands in the National Forests of northeastern California produce forage for livestock during a 4- to 5-month season—the season when forage at home, on foothill ranges of the Sacramento Valley, is dry and of lower grazing value. These mountain rangelands also support deer and antelope and are important as producers of timber, water, and recreation. Therefore, these ranges should be managed on an ecologically sound basis.

The history of early grazing suggests that range management was not ecologically sound (74th Congress 1936). Rather, rangelands of northeastern California were badly mismanaged. Overstocking led to overgrazing of the range, and with improper seasonal use resulted in severe deterioration of the range resource.[1]

Traditionally, in these mountain rangelands, cattle were brought to the summer range as soon as snow conditions permitted. They were left to graze the range at will during summer and then gathered for the drive home just before the fall storms. This "free choice" grazing program (hereafter referred to as season-long grazing) is still used on most of the ranges.

In the past, little attention was paid to the prime elements of livestock grazing management: stocking rates, season of use, livestock distribution, and frequency of use. A range improves or deteriorates and livestock production is efficient or inefficient as a result of manipulation of these four elements. All other influences on range health and production efficiency are generally beyond the control of the range manager or ranch operator.

After the National Forests in northeastern California were established, management aimed at moderate use of the ranges. Stocking rates were gradually reduced, season of use was shortened, and techniques of improving livestock distribution were employed. The ranges continued to be grazed season-long, however. Some improvement in range condition was achieved in those areas not preferred by livestock, but the preferred grazing areas did not improve. On many range allotments, improved livestock grazing management was needed to arrest and then reverse the downtrend in range condition, increase range livestock production, and enhance other range values.

The Harvey Valley allotment on the Lassen National Forest was chosen as a representative area on which to test a rest-rotation grazing program for range improvement. The program was begun in 1954, after 3 years of preparatory work.

Records of livestock use on the Harvey Valley allotment date from 1870. From then until 1906, when the Lassen National Forest was established, about 7,200 animal-unit months (one animal-unit month (A.U.M.) represents one 1,000-pound cow grazing for 1 month) of grazing were obtained from the allotment each season. After 1906, except for a temporary increase from 1914 to 1918, stocking rate and season of use were gradually reduced, but the health of the range declined until by 1951 the animal-unit months of grazing were only one-third of that obtained in the late 1800's *(fig. 1)*. Nearby allotments have a similar history of early use and reduced grazing capacity. Harvey Valley was the first Forest Service allotment to be placed under rest-rotation grazing. Nearby allotments have continued to be grazed season-long.

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[1] Hormay, A. L. *Management and study plan—Harvey Valley Experimental Range.* 1954, rev. 1956. (Unpublished report on file at Pacific SW. Forest & Range Exp. Sta., U.S. Forest Serv., Fresno, Calif.)

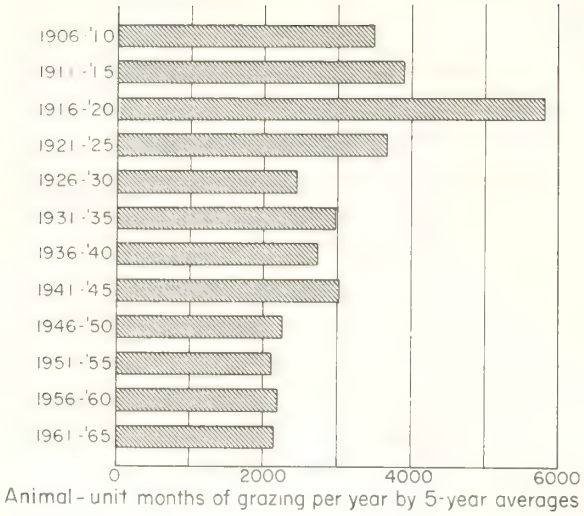



**Figure 1**—Grazing use on Harvey Valley allotment, in the Lassen National Forest, northeastern California, showed fluctuations during the period 1906-1965.

This paper reports an evaluation of progress observed on the Harvey Valley allotment to 1966. It summarizes findings in (a) comparative range health and apparent condition trends, (b) cattle weight gains, and (c) cost/return analysis from the standpoint of both the Forest Service and the permittee. In the cost analysis, the basis for comparison was the estimated cost of managing the Harvey Valley allotment under a season-long grazing program, rather than costs on a nearby allotment.

# THE HARVEY VALLEY AREA

Harvey Valley and nearby allotments are in the southern Cascades, in a region characterized by valleys with broad, fairly level lowlands and terraces between volcanic peaks *(fig. 2).* Elevations vary from 5,600 feet to about 7,500 feet.

## Climate

Rather dry summers and cold wet winters with considerable snowfall are the rule. Summer precipitation makes up less than 3 percent of the yearly mean of 18.4 inches (Ratliff and Reppert 1965); 20 percent comes in fall and a similar amount in spring, whereas winter accounts for 57 percent. Shortages in seasonal and yearlong precipitation are frequent. The area had drought in one-third of the years from 1935 through 1963, and spring drought in more than half of the years of that period.

Average monthly air temperatures are usually below freezing during November through February, at or near freezing in March, and above freezing in all other months. Hormay and Talbot (1961) reported a low of -27°F. in January 1937 and a high of 98°F. in July of 1946.

## Soils and Vegetation

Soils of the area are quite diverse, ranging in thickness from a few inches to more than 5 feet. Surface textures range from loamy sand in the higher areas to clay in the lower areas. Calcareous hardpans developed in some soils a few inches to 2 feet or more below the surface. On the slopes of the mountains, formed from Pleistocene and recent basalt, soils are primarily residual. Soils on the lowlands formed over ancient lake and more recent alluvial deposits.

Meadows in the drainage bottoms are watered by winter snows and spring runoff. Most meadows are on moderately deep to deep soils; hardpans are found at some of the ephemeral lake sites.

Vegetation consists of five principal types. The silver sagebrush *(Artemisia cana)*[2] type grows slightly above the meadows, but the soil is often covered with water early in spring. Here the most important grasses are Nevada blue grass *(Poa nevadensis)* and bottlebrush squirreltail *(Sitanion hystrix).* Soils are generally dark-colored and moderately deep, with an occasional hardpan at moderate depth.

The black sagebrush type *(Artemisia arbuscula)* is usually intermediate between the silver and big sagebrush types *(Artemisia tridentata).* Soils under black sagebrush are usually very shallow and often have a calcareous hardpan. This type of soil is generally the least productive of forage and has the least potential for improvement. The most abundant grasses here are Sandberg bluegrass *(Poa sandbergii),* and bottlebrush squirreltail; there is some Idaho fescue *(Festuca idahoensis),* western needlegrass *(Stipa occidentalis),* and Junegrass *(Koeleria cristata).*

Big sagebrush occupies fairly deep, well-drained soils. Idaho fescue, bottlebrush squirreltail, Sandberg

[2]Scientific names follow *A California Flora,* by P. A. Munz and D. D. Keck. Berkeley: University of Calif. Press. 1959.

Figure 2—Broad, level lowlands and volcanic peaks are typical of this view of the Harvey Valley area, taken June 15, 1967.

bluegrass, and various needlegrasses are the principal grasses in this type. Ross sedge *(Carex rossii)*, an important grasslike plant, occurs here and is well liked by cattle.

The open grassland type, sometimes called the shorthair sedge *(Carex exserta)*–bunchgrass type, occupies a physiographic position very close to that of big sagebrush. The two types often blend together and the soils are similar. Shorthair sedge often dominates this vegetation type, but bunchgrasses may dominate and even exclude it.

On the lower slopes of the mountains, vegetation is the ponderosa pine *(Pinus ponderosa)*–big sagebrush transition type. Idaho fescue, various needlegrasses, and bottlebrush squirreltail are the major forage components in most of this zone. Soils are usually moderately shallow to a fractured bedrock, and produce good forage where tree canopy and needle layers are not too heavy.

In the pine type proper, the slopes are steeper than in the transition zone. Soils are very similar in depth, texture, and color. Where the canopy is open, good forage is produced. Perennial bromes *(Bromus)* are fairly abundant on the higher elevations.

In the fir *(Abies)* type, important forage plants include brome, bottlebrush squirreltail, and needlegrasses. Openings are often occupied by big sagebrush, and greenleaf manzanita *(Arctostaphylos patula)* may form dense stands on burnt areas.

Additional information on soils and vegetation of the area was reported by Hormay and Talbot (1961).

## REST-ROTATION GRAZING

The principles of rest-rotation grazing management were developed through research by Hormay and Talbot (1961) at the Burgess Spring Experimental Range. Rest-rotation controls all four elements of grazing management and is intended to provide for both ecological and cultural range improvement.

The basic principles of rest-rotation grazing have been discussed in detail by Hormay (1970). They may be summarized as follows:

- A major cause of range deterioration is selective close grazing of plants and range areas in similar yearly patterns of use.
- The only effective way to control this selective grazing by livestock and counter its harmful effects is to rest these areas from grazing at appropriate intervals.
- To encourage maximum rate and degree of improvement in range condition, the exact prescription of rest and grazing must be correlated with the growth and reproduction requirements of the key species of a specific range or allotment.

In preparation for the test of rest-rotation begun in 1954, the Harvey Valley allotment (consisting of 34,775 acres) was cross-fenced into five range units of about equal capacity. The prescription called for each range unit to be rested two full grazing seasons out of five. In addition, two half seasons of rest were planned for each range unit. Thus one full season and two half seasons were available for grazing use. Cattle were confined to assigned range units during periods of grazing.

The prescription was based on the requirements of Idaho fescue. After a full season of use, a given range unit was rested a full season to permit recovery of plant vigor. The third season the unit was rested until midseason to permit plants to ripen seed and then

was fully grazed in order to trample seed into the soil and to allow maximum forage utilization and livestock production. During the fourth year of the rotation, the range unit was rested to permit seedlings to become established. In the fifth year, it was grazed moderately to midseason and rested the second half of the season as a further aid to seedling establishment. In the following year the unit was again grazed season-long, and the 5-year cycle was repeated. The prescription provided for emergency use of those range units scheduled for rest. Their use was permitted in years of low forage production, thus assuring ample feed for the cattle for the full grazing season. Grazing of units scheduled for rest would tend to slow the rate of range improvement. However, their use was allowed only late in the grazing season when the effects of grazing are least severe.

From 1954 through 1962 the season of use on Harvey Valley was June 1 to September 30. Since 1963, the closing date has been October 31. During the period of study, however, there was no increase in the total animal-unit months of grazing obtained each season from the allotment.

## Expected Responses

Rest-rotation grazing and the improvement program for Harvey Valley were expected to double the grazing capacity in 20 years, or by 1974.[3] This increase was to come from three sources: rest-rotation grazing (43 percent), cultural practices (42 percent), and logging (15 percent).

Specific changes in plant, soil, and stand characteristics were expected to produce an improved condition and greater grazing capacity.

The plant characteristics were. . .

- Greater vigor of established plants as indicated by size of plant parts.
- Greater seed production.
- Higher nutrient content.

The soil characteristics were. . .

- More litter cover and less exposed bare soil.
- Faster water absorption and less soil compaction.

The stand characteristics were. . .

- Larger cover percentages for desirable species.
- Better species composition, indicating a higher successional stage.
- More seedlings of desirable species.

[3]Hormay, A. L. 1954, rev. 1956 (unpublished report on file at Pacific SW. Forest & Range Exp. Sta., U.S. Forest Serv., Fresno, Calif.)

In addition, it was expected that the rotation of grazing would permit spraying and seeding without the restriction on use of land units otherwise required for this purpose. Seedings were expected to be maintained without special fencing to separate them from areas of native range.

## Evaluation of Program

From 1954 through 1962 almost all Forest Service evaluation of the effectiveness of rest-rotation grazing was made in Harvey Valley. Collection of comparable data (livestock as well as vegetation) from other allotments–although originally intended–was not accomplished owing to lack of adequate funding.

Only by comparisons with other ranges is it possible to learn whether rest-rotation grazing has been doing the job for which it was designed; specifically, to improve range health while maintaining an acceptable level of livestock production. Therefore, from 1963 to 1966, special effort was made to evaluate the effects and value of rest-rotation grazing as used at Harvey Valley through comparisons with nearby allotments.

The evaluation of range health was made by means of a scoring system that allowed comparisons of plots in Harvey Valley with comparable plots in other allotments. On the basis of the scoring, the apparent condition trend was estimated.

## Methods and Logic

Following the system described by Ratliff and Reppert (1966), 26 pairs of plots, each 1/4 or 1/2 acre, were set up in several vegetation types within Harvey Valley and four nearby allotments. Plot pairs formed two position groups–boundary plots and interior plots. The members of boundary pairs were usually within 100 yards of each other and were placed to avoid unusual cattle concentration areas or pathways along fence lines. The members of interior pairs were from 1 to several miles apart. The 26 plot pairs also fell into four generalized vegetation types–hereafter referred to as *major vegetation types.* Nine were in timber-bunchgrass, seven in open grassland, and six in the open shrub-grass type. The other four plot pairs were in meadows.

Comparison of a Harvey Valley plot with its "partner" in another allotment required two assumptions: First, given the same management, the site capability of either member of a pair of plots was the same for producing a general community of plants. Second, both members of a pair of study plots were

producing a quantity of herbage and a quality of plant community at some unknown degree below their natural capabilities. On the basis of these assumptions, certain differences between the members of a plot pair provided an indication of the "relative" range conditions—the conditions of plots grazed under rest-rotation as compared to that of plots grazed season-long. Relative range condition for each pair of plots was determined by rating the plots on nine major condition characteristics reflecting the expected goals of rest-rotation grazing.

In order to use the results of the rating as an estimate of apparent trend in range condition on the Harvey Valley plots it was necessary to assume also that: first, the grazing program and range condition were essentially the same on a pair of plots at the time rest-rotation grazing was started in 1954; and second, the trend in range condition was near static after 1954 on nearby allotments under season-long use. Statements in this report that imply responses of plants and other elements of range health are also based upon these assumptions.

# TRENDS IN RANGE HEALTH AND CONDITION

As has been stated, some influences on range conditions are outside management control, and we do not have data on these. One climatic influence on the results of the evaluation may be noted, however. Rest-rotation was in full operation at Harvey Valley near the end of a period of abundant precipitation. The status of range condition in Harvey Valley and the apparent condition trends, relative to neighboring allotments, were determined after the most severe period of drought since 1936. Prolonged, severe drought is not conducive to range condition improvement, and the range resource may have made a slower response to rest-rotation at Harvey Valley than it would have under better conditions.

## *Relative Range Condition*

A relative condition score was developed for each plot-pair test, using a 100-point maximum rating. Nine characteristics were rated as follows: basal cover, 25 points; plant vigor, 20 points; species composition, 15 points; litter cover and herbage yield, 10 points each; and bare soil, water absorption, soil compaction, and perennial grass seedlings 5 points each. The individual plot scores *(table 1)* were arrived at by assigning a number of points for each characteristic measured to each member of a plot pair and then summing the points for all characteristics. All nine characteristics were not measured on all plot pairs; no points were assigned for characteristics not measured.

The points assigned to a plot for a particular characteristic reflected the number of counts of significant differences in the characteristic that were favorable to each plot. For example, plant vigor was assessed by using five indicators. Let us say that four of the differences between a pair of plots favored Harvey Valley and one the nearby allotment. Then, 16 points were given to the Harvey Valley plot and four to the other plot.

Absolute or true range condition cannot be measured from these scores. Instead, they amplify the important differences between plot pairs to show

Table 1—*Relative range condition scores of 26 pairs of comparable plots in Harvey Valley and nearby allotments, 1964-66, by major vegetation types; scores based on a 100-point, 9-characteristic rating system*

| Timber bunchgrass | | | Open grassland | | | Open shrub-grass | | | Meadow | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Plot pair | Harvey Valley plot | Other plot | Plot pair | Harvey Valley plot | Other plot | Plot pair | Harvey Valley plot | Other plot | Plot pair | Harvey Valley plot | Other plot |
| 4 | 9.5 | 30.5 | 16 | 71.2 | 13.8 | 2 | 57.1 | 27.9 | 49 | 77.7 | 12.3 |
| 12 | 38.8 | 36.2 | 25 | 82.9 | 17.1 | 3 | 26.9 | 48.1 | 70 | 56.9 | 38.1 |
| 13 | 83.7 | 6.3 | 41 | 55.1 | 14.9 | 17 | 64.6 | 10.4 | 78 | 38.4 | 51.6 |
| 14 | 43.3 | 41.7 | 47 | 63.7 | 21.3 | 18 | 33.6 | 41.4 | 82 | 52.9 | 37.1 |
| 15 | 51.7 | 33.3 | 64 | 78.0 | 22.0 | 71 | 43.9 | 36.1 | | | |
| 19 | 71.7 | 8.3 | 79 | 64.3 | 20.7 | 72 | 28.3 | 61.7 | | | |
| 20 | 67.6 | 12.4 | 80 | 57.3 | 22.7 | | | | | | |
| 21 | 53.5 | 21.5 | | | | | | | | | |
| 81 | 56.0 | 24.0 | | | | | | | | | |
| Av. | 52.9 | 23.8 | | 67.5 | 18.9 | | 42.4 | 37.6 | | 56.5 | 34.8 |

whether a given plot is in better or worse condition than its partner.

Relative range condition scores *(table 1)* were higher for the plot under rest-rotation in 21, or 81 percent, of the 26 comparisons. For all seven of the open grassland plot pairs, scores were higher under rest-rotation, and the average score of the season-long plots was only 28 percent of the average score of the rest-rotation plots. In the timber-bunchgrass type only plot pair 4 scored higher for the season-long member. Eight others were higher under rest-rotation, and the average score of the rest-rotation plots was twice as large as for season-long grazing. In the meadow type, plot pair 78 (undrained basin site) scored lower for the Harvey Valley member. The other three meadow pairs scored higher for the plot under rest-rotation, and the average score for the season-long plots was 62 percent of that for meadows on Harvey Valley. For the open shrub-grass type, half of the scores were higher for the season-long members of the plot pairs. The average score of the season-long plots was 89 percent of the score for the plots under rest-rotation.

Thus, the open grasslands have apparently made greatest gains in relative range condition under rest-rotation, followed by the timber-bunchgrass and meadow types. The better condition of the open grasslands is very apparent on the Harvey Valley member of plot pair 79 *(fig. 3)*. The scores of plot pairs 17 and 72 are worth noting. Plot pair 17 is on a silver sagebrush site that is heavily used under both types of grazing. Plot pair 72 is on a less productive, more lightly grazed big sagebrush site. Hence, although, on the average, the open shrub-grass type has not done as well as the others, the more productive sites within the general type apparently are improving under rest-rotation grazing.

## Apparent Trend in Range Condition

The differences between plots can be seen more easily to show a trend if they are analyzed by plot location *(table 2)*. The plots under rest-rotation along the boundary with the Champs Flat allotment—where the fence was put in at the start of rest-rotation—were generally in better condition than those grazed season-long, indicating an improving range condition on the Harvey Valley allotment. Seven plot pairs are along this boundary, and for six of them the relative condition scores were higher for the rest-rotation plot. Only on plot pair 18 was the score higher for the season-long plot.

Table 2—*Average relative range condition scores of comparable plot pairs, by location*

| Location | Grazing treatment | | Number of plot pairs |
|---|---|---|---|
| | Rest-rotation | Season-long | |
| Champs Flat boundary | 59.5 | 20.6 | 7 |
| Lower Pine Creek boundary | 55.3 | 28.1 | 3 |
| Grays Valley boundary | 43.0 | 30.0 | 5 |
| Interior of allotments | 57.4 | 30.3 | 11 |

Along the other boundaries and in the interiors of the allotments, differences in pattern and duration of season-long use may have resulted in different conditions at the time rest-rotation was started. Still, apparent trend in condition on most of the plots under rest-rotation is upward. Only two of the other eight boundary plot pairs had higher scores on the season-long plot. On only two of the 11 interior plot pairs were scores higher for season-long plots.

The upward trend in relative range condition on Harvey Valley does not necessarily imply that condition trend is down on neighboring allotments; it may in fact be up, but if so, it is not as pronounced as on Harvey Valley.

Findings of an upward trend in range condition on Harvey Valley tend to be contradicted by results from permanent condition and trend transects.[4] These results indicate that condition trend was down between 1957 and 1963 on Harvey Valley. With three consecutive years of drought (1959-60-61) such a decline is not unlikely. But, if range condition of Harvey Valley is now better than that of neighboring allotments, an important conclusion may be drawn. The Harvey Valley allotment was not hurt as much by the drought and was able to recover and respond more rapidly with good years, or it was in better condition by the start of the drought than the neighboring allotments. Under either or both of these circumstances, progress in improving range condition is being made at Harvey Valley.

### Range Condition Characteristics

The rating scores give a broad picture of the results of the rest-rotation grazing program. Data from the studies that contributed to the point ratings serve to

[4]These are permanently marked belt transects established on a variety of range sites. They were first measured in 1957 and again in 1963. (The unpublished data are on file at Pacific SW. Forest & Range Exp. Sta., Fresno, Calif.)

**Figure 3**—Comparable plot pair No. 79 is of the open grassland type. *Above,* Harvey Valley; *below,* Gray's Valley, in 1965.

amplify these findings and suggest the areas in which most progress has been made.

*Plant vigor*–Five measurements were taken on important species–vegetative shoot length and weight, seed stalk length, and seedhead length and weight.

Idaho fescue vegetative shoot weight and length were 16 and 26 percent greater on the Harvey Valley plots *(table 3).* Length of both seed stalks and seedheads was significantly greater under rest-rotation. There was no difference, however, in the weights of the seedheads. As a further indication, results of regrowth studies using plant cores showed that some Idaho fescue plants from Harvey Valley have a better supply of root reserves than do those from the allotments grazed season-long. Thus, rest-rotation grazing has resulted in improved vigor of the key forage species.

The vegetative shoots of western needlegrass were 15 percent longer and 26 percent heavier *(table 3)* under rest-rotation. Although there were no differences in the other indicators, the results suggest a generally favorable response to management.

*Perennial grass seedlings*–Seedlings were more plentiful under rest-rotation grazing in 1965–a bumper seedling year both in and around Harvey Valley. Of 19 upland plot pairs examined in 1965, 11 had significantly higher seedling frequencies for the rest-rotation plot. Only two had higher frequencies for the season-long plot, and for six there was no difference. The average difference (2.05 more seedlings under rest-rotation per 100 nearest-plant observations) was significant by chi-square test at the 95-percent probability level. Thus, the data indicate that–given a good seedling year–more perennial grass seedlings are likely in upland areas under rest-rotation, increasing the chance for new plants to become established.

*Herbage yield*–Herbage yield was measured on 10 comparable plot pairs in the open grassland, open shrub-grass, and meadow types. Results indicate that yield of herbage increased under rest-rotation grazing *(table 4).* On open grassland and open shrub-grass plot pairs, yield under rest-rotation was one-third more than the yield under season-long grazing. For meadows, yield was about one-fifth more under rest-rotation.

Assuming that range condition was the same on each plot of a pair at the start of rest-rotation, the yield data allow estimation of the present grazing capacity of the Harvey Valley allotment. In 1951, the estimated grazing capacities for the open grassland, open shrub-grass and meadow types were 118.8, 636.8, and 599.2 A.U.M., respectively. All plot pairs considered, the increases in yield are 33.7, 35.6, and 12.3 percent, respectively, giving an estimated increase of 340 A.U.M. This is about 15 percent of the total 1951 allotment capacity (2,060 A.U.M., timber-bunchgrass type included).

*Litter cover and bare soil*–Litter cover increased under rest-rotation *(table 4).* Sixteen of the 26 plot-pair comparisons showed more litter cover under rest-rotation, three the reverse, and seven no difference.

Bare soil, gravel, rock, and wood were expected to be better covered by litter and plants under rest-rotation. More bare soil was exposed under season-long grazing on 16 of the 26 plot pairs compared, and less on five. Since the increase in litter cover is about equal to the decrease in bare soil *(table 4),* it appears

Table 3–*Differences in plant vigor indicators for Idaho fescue and western needlegrass under rest-rotation (RR) at Harvey Valley and season-long (SL) grazing at nearby allotments*

| Item | Vegetative shoot weight | Vegetative shoot length | Seedhead length | Seed stalk length | Seedhead weight |
|---|---|---|---|---|---|
| | *Mg.* | *Ft.* | *Ft.* | *Ft.* | *Mg.* |
| | IDAHO FESCUE | | | | |
| Average size, RR | 100.07 | 0.52 | 0.36 | 1.80 | 222.92 |
| Average size, SL | 79.03 | .45 | .34 | 1.74 | 220.16 |
| Difference | 21.04*** | .07*** | .02*** | .06** | 2.76 |
| | WESTERN NEEDLEGRASS | | | | |
| Average size, RR | 195.00 | .54 | .91 | 1.40 | 480.22 |
| Average size, SL | 143.96 | .46 | .87 | 1.38 | 492.06 |
| Difference | 51.04* | .08*** | .04 | .02 | -11.84 |

*Statistically significant at 20 percent level of probability by paired t test.
**Statistically significant at 10 percent level of probability by paired t test.
***Statistically significant at 5 percent level of probability by paired t test.

Table 4—*Differences in herbage yield, litter, bare soil, water absorption, and soil compaction under rest-rotation at Harvey Valley and season-long grazing at nearby allotments*

| Grazing program | Herbage yield | Litter cover | Bare soil | Water absorption | Soil compaction | |
|---|---|---|---|---|---|---|
| | | | | | Spring | Fall |
| | *Lb./acre* | *Pct.* | *Pct.* | *Min./inch* | *—— P.s.i.——* | |
| Rest-rotation | 1,238.2 | 53.8 | 21.8 | 6.1 | 283.6 | 432.9 |
| Season-long | 1,050.9 | 46.4 | 28.9 | 7.0 | 297.5 | 484.1 |
| Difference | 187.3** | 7.4*** | -7.1*** | - .9*** | -13.9 | -51.2* |

*Statistically significant at 20 percent level of probability by paired t test.
**Statistically significant at 10 percent level of probability by paired t test.
***Statistically significant at 5 percent level of probability by paired t test.

that the area of exposed soil is becoming less under rest-rotation with a corresponding increase in litter cover.

Although individual plot pair differences occurred for gravel, rock, and wood, there were no differences between methods of grazing for these characteristics.

*Soil characteristics*–Water absorption is faster under rest-rotation. Half of 24 tests of water absorption rates showed significant differences; in these, it took 1.8 minutes less for 1 inch of water to be absorbed on the plots under rest-rotation.

Soil compaction, an important factor on many rangelands, appears to be less important in the Harvey Valley area. Soils were less compacted in the fall *(table 4)* on plots under rest-rotation, but no difference between plots was found in the spring. Apparently, frost action tends to break up compacted layers on many sites. Also, on 15 upland plot pairs we found no difference due to method of grazing in the average within-plot increase in compaction between spring and fall.

Table 5—*Average differences between paired plots*[1] *in basal cover for plants of primary, secondary, and low value by major vegetation type*

| Vegetation type | Plant grouping | | | |
|---|---|---|---|---|
| | Primary | Secondary | Low value | All plants |
| | *Percent* | | | |
| Timber-bunchgrass | 0.05 | 0.18* | -1.76 | -1.53* |
| Open grasslands | 1.32*** | .58* | -1.62* | .29 |
| Open shrub-grass | .44* | .13 | 1.28 | 1.86* |
| Meadows | 3.23*** | -.05 | -.31 | 2.88* |
| All types | .97*** | .25** | -.80 | .42 |

[1]Season-long plot value subtracted from rest-rotation plot value.
*Statistically significant at 20 percent level of probability by paired t test.
**Statistically significant at 10 percent level of probability by paired t test.
***Statistically significant at 5 percent level of probability by paired t test.

*Basal cover*–Basal cover of desirable species should increase as a result of better plant vigor, greater seedling numbers, and better soil surface conditions under rest-rotation grazing, and such an increase is evident.

The meadows show the most favorable responses in basal cover to rest-rotation grazing *(table 5)*. The open grasslands have also responded well, but only minor gains have been made in the timber-bunchgrass and open shrub-grass vegetation types.

Since there was no significant difference in cover of low-value species and no significant difference in total plant cover, either primary or secondary species have replaced some low value ones or have advanced into previously unoccupied soil on the plots under rest-rotation. Either way it is a step toward improvement in the resource.

Thus far, bottlebrush squirreltail has been the grass most responsive to rest-rotation grazing. Under rest-rotation, bottlebrush squirreltail made up three times more of the cover than under season-long grazing *(table 6)*. Idaho fescue has not shown nearly as much response, although the difference (22 percent) was significant.

Junegrass was encountered in basal cover studies on six pairs of plots *(table 6)*. In five plot pairs there was significantly more cover of Junegrass under rest-rotation than under season-long grazing. Considering the small number of tests and the large difference in average cover values, Junegrass appears to be responding well to rest-rotation.

All upland plot pair tests considered, western needlegrass, Sandberg bluegrass, Ross sedge, and shorthair sedge have shown no response in basal cover to rest-rotation *(table 6)*, but important differences between members of plot pairs were noticeable.

It is likely that the seed dispersal mechanism (wind), and high seedling vigor of bottlebrush squir-

Table 6—*Differences between paired upland plots in basal cover of some important plant species and species groups*

| Species or Group | Average basal cover | | | |
|---|---|---|---|---|
| | Plot pairs | Rest-rotation plots | Season-long plots | Differences RR-SL |
| | *No.* | *— Percent —* | | *Percent* |
| Bottlebrush squirreltail | 19 | 0.35 | 0.11 | 0.24** |
| Idaho fescue | 17 | 1.25 | 1.02 | .23* |
| Junegrass | 6 | .39 | .06 | .33** |
| Western needlegrass | 18 | .53 | .56 | -.03 |
| Sandberg bluegrass | 10 | .60 | .51 | .09 |
| Ross sedge | 17 | 1.03 | .95 | .08 |
| Shorthair sedge | 8 | 3.52 | 3.03 | .49 |
| All grasses | 22 | 2.30 | 1.67 | .63** |
| All grasslike plants | 22 | 2.13 | 1.86 | .27* |
| Forbs[1] | 21 | .43 | .85 | -.42 |
| Shrubs | 22 | 7.07 | 7.60 | -.53 |

[1]No forbs were found in basal cover on one upland plot pair.
*Statistically significant at 20 percent level of probability by paired t test.
**Statistically significant at 5 percent level of probability by paired t test.

reltail account for its noticeably good response to rest-rotation. Slower responses of other important species may reflect their relative sensitivity to grazing, competitive ability, and requirements for seedling establishment.

The absolute differences—0.24 and 0.23 percent *(table 6)*—in basal cover of bottlebrush squirreltail and Idaho fescue are small, but they are nevertheless important. In 1957—a drought year—Idaho fescue produced 1.75 and bottlebrush squirreltail 3.81 grams of herbage per square inch of live basal area. With such yields, the differences in cover mean an additional 56 pounds of Idaho fescue and 126 pounds of bottlebrush squirreltail per acre on the plots under rest-rotation.

On the four pairs of meadow plots, basal cover of grasslike plants was greater under rest-rotation grazing. Except for the ephemeral lake site, there was less basal cover of forbs. Buttercup *(Ranunculus)* species made up much of the forb values on the plots grazed season-long. No differences in cover values of the clover *(Trifolium longipes)* were found in the meadows. These results indicate that grasslike plants are replacing some forbs on those plots under rest-rotation grazing. Successionally, this is a desirable trend.

*Species composition*—Data on species composition reflects the relative competitive stance of a particular species and the kind of competition it must face. Hence, if the better plant species are increasing and spreading out under rest-rotation, this would suggest that under freer competition, succession is proceeding to a higher stage, as the better "climax" species gain stronger control of the site.

Evidence from our species composition data show that (1) relative to plots grazed season-long, the competitive position of primary species is stronger, of secondary species is as strong, and of low value species is weaker under rest-rotation *(table 7);* (2) on upland areas, some of the better grasses and grasses generally are in relatively stronger competitive positions under rest-rotation *(table 8);* (3) the position of forbs is much stronger under season-long grazing, but those of grasslike plants and shrubs are equal; and (4) under rest-rotation, grasslike species presently have the upper hand on meadows. Thus in general, the evidence supports the expectation of a better species composition and hence a higher successional stage with rest-rotation grazing.

Hormay and Talbot (1961) stated, "In effect, grazing is eliminated as an environmental factor under rest-rotation grazing." In actuality, however, grazing is an important factor under rest-rotation grazing. Although overgrazing of desirable plants is avoided, periods of full use are planned so that less desirable as well as the most desirable vegetation is grazed. Grazing is employed as a method of planting seed. During the rest periods plants regain vigor, seedlings become established, and the species are free to compete with each other. Thus grazing and rest are combined to permit succession to proceed on a course toward more desirable climax species.

Ellison, *et al.* (1951) stated, "Natural vegetation on high range-watersheds in good condition consists of a mixture of many species, practically all of which are perennials." Under rest-rotation, the number of annual plant species present on study plots made up no larger percentage of the total number of species

Table 7—*Average differences between paired plots*[1] *in species composition in percent of primary, secondary, and low value plants, by major vegetation type*

| Vegetation type | Plant grouping | | | |
|---|---|---|---|---|
| | Primary | Secondary | Low value | Others |
| | *Percent* | | | |
| Timber-bunchgrass | 5.53* | 1.43 | -6.96* | 0.00 |
| Open grasslands | 9.05* | 3.60 | -12.67* | .02 |
| Open shrub-grass | 1.86 | -1.38 | -.54 | .06 |
| Meadows | 20.73* | -4.53* | -16.14* | -.06 |
| All types | 7.96* | .46 | -8.43* | .01 |

[1]Season-long plot value subtracted from rest-rotation plot value.
*Statistically significant at 5 percent level of probability by chi-square test

Table 8—*Differences in species composition between paired upland plots, in percent of some important plant species and species groups*

| Species or group | Number of plot pairs | Average percent composition | | |
|---|---|---|---|---|
| | | Rest-rotation | Season-long | Difference, RR-SL |
| Bottlebrush squirreltail | 21 | 6.68 | 3.98 | 2.70* |
| Idaho fescue | 19 | 10.29 | 8.60 | 1.69 |
| Junegrass | 10 | 3.01 | .62 | 2.38* |
| Western needlegrass | 21 | 18.56 | 19.90 | -1.34 |
| Sandberg bluegrass | 11 | 5.14 | 4.25 | .89 |
| Ross sedge | 17 | 11.62 | 11.45 | .17 |
| Shorthair sedge | 9 | 25.39 | 23.57 | 1.82 |
| All grasses | 22 | 39.61 | 33.65 | 5.96* |
| All grasslike plants | 22 | 21.08 | 19.91 | 1.17 |
| Forbs | 22 | 25.24 | 30.50 | -5.26* |
| Shrubs | 22 | 14.07 | 15.93 | -1.86 |

*Statistically significant at 5 percent level of probability of chi-square test.

encountered than it did under season-long grazing. In terms of species composition, however, annual plants were 60 percent more prevalent under season-long grazing in the open grasslands *(table 9)*. For the meadows and open shrub-grass type, annual plants were about one-third more prevalent. Thus we have additional evidence that the wet meadow, open shrub-grass, and open grassland vegetation types are in higher stages of succession and better range condition under rest-rotation than under season-long grazing.

*Nutrient status of soils and leaf tissues*—Soil and plant nutrient studies were made, but were not included in the point ratings. Results from soil analyses indicate that rest-rotation grazing at Harvey Valley has had little effect on soil nutrient status. Phosphorus was the only nutrient for which a significant difference was found. Higher phosphorus content on the Harvey Valley plots occurred in the second soil horizon of timber bunchgrass plots.

There was more calcium (0.0l percent) and more magnesium (0.01 percent) in leaf tissue from the timber-bunchgrass plots under rest-rotation. However, under both grazing programs, the content of calcium and magnesium was above the livestock requirements given by Morrison (1957). Hence, it is unlikely that such differences could affect cattle gains. No differences were found for phosphorus, sodium, or potassium.

Table 9—*Difference between paired plots in average percent composition of annual plants, by major vegetation type*

| Major vegetation type | Average percent composition | | |
|---|---|---|---|
| | Rest-rotation | Season-long | Differences RR-SL |
| Wet meadow | 8.9 | 12.2 | -3.3* |
| Open shrub-grass | 22.3 | 29.2 | -6.9* |
| Open grassland | 14.6 | 23.3 | -8.7* |
| Timber bunchgrass | 11.6 | 13.0 | -1.4 |

*Statistically significant at 5 percent level of probability by chi-square test.

### Effects of Cultural Improvement Work

Range seeding and sagebrush control at Harvey Valley were planned to complement the effects of management in improving the resource. Sagebrush was controlled on 3,655 acres, and 497 acres were reseeded. This work was accomplished without requiring periods of nonuse, and the seedings have been maintained without special fencing.

The actual extent to which this cultural work has contributed to improvement of areas of native range cannot be determined. However, the seeded areas are highly preferred (Ratliff 1962), and tend to lessen the grazing pressure on native range areas during the early part of the grazing period.

## Discussion

Rest-rotation grazing is doing much of what was expected at Harvey Valley. It seems clear that rest-rotation grazing is ecologically superior to season-long grazing; and that range health at Harvey Valley relative to nearby allotments is better, and range condition trend upward, because of rest-rotation grazing.

The response to rest-rotation has not been as dramatic at Harvey Valley as in some other areas of the West. For example, Kirk[5] reported a 10-percent increase in the allowable number of cattle after only

[5]Kirk, P. A. 1968. *Rest-rotation grazing in southwestern New Mexico.* Paper presented at annual meeting, American Society of Range Management, Albuquerque, New Mexico, Feb. 1968.

1 year of rest-rotation grazing. This was on a range grazed yearlong and with only 9 inches of precipitation annually.

There are at least two possible reasons for what appears to be a slow response at Harvey Valley. First, there was drought in 5 of the first 9 years of rest-rotation. To provide forage for the cattle this necessitated grazing units which were scheduled to be rested. Using "rested" units for this purpose is an accepted practice under rest-rotation grazing (Hormay 1970). Second, seedlings must become established if there is to be a rapid increase in basal area of perennial bunchgrass plants (Hormay and Talbot 1961). As in much of California, the summers at Harvey Valley are usually hot and dry. This, along with frequent spring drought, means few favorable years for seedling establishment.

In view of the conditions working against improvement, rest-rotation grazing has performed well on Harvey Valley during the first decade of its use. More favorable weather should bring greater and more rapid improvement in the future.

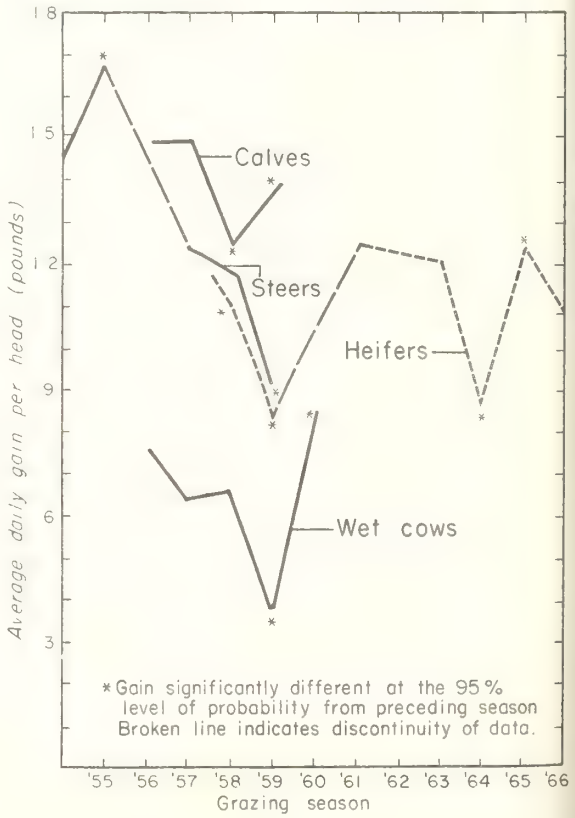
# CATTLE WEIGHT GAINS

To the resource manager, improvement in range health indicates the worth of a particular system of grazing management, but to ranchers the amount and quality of beef produced is the final proof. As has been shown, rest-rotation grazing is good for the resource. The program has also produced acceptable cattle weight gains at Harvey Valley.

In the collection of data on cattle gains presented here, except where noted, cattle were weighed individually. Weights were obtained on an unshrunk basis from 1954 through 1959, but starting in 1960 animals were held overnight in the corrals without food or water. Tests made with steers in 1954 indicated that shrinkage overnight would result in about 4 percent reduction in weight, and early data were adjusted by this percentage to make them more comparable to recent data. Cattle showing weight losses for a full season were assumed to have been sick and were therefore excluded from computations.

## *Broad Trends*

Over the period of rest-rotation grazing (1954-1966, inclusive) individual animal weight gains on the Harvey Valley allotment have shown no long-term tendency either to increase nor decrease. Gains were often significantly higher or lower from 1 year to the next *(fig. 4)*. The depression of heifer gains in 1964 resulted from markedly lower gains than usual after midseason—they just held their own. Lower heifer gains in 1966 are probably the result of drought that year. Drought was probably the major factor also in the drop in steer and heifer gains in 1959 as compared with 1958. The sharp increase in cow gains in 1960 over 1959 reflects the sale of the calves at midseason, resulting in greater cow gains than usual during the second half of the season. The lowest (465 lbs.) and highest (703 lbs.) average starting weights of steers were noted in 1957 and 1959, respectively. Hence, although starting weight was probably a factor, age and condition of the steers at the start of the season probably determined the change evident in yearly differences for 1954-55 as compared to 1957-59.



Large differences in the quantity of forage available from year to year may be expected. Hormay and Talbot (1961) found the yield per acre to be 37 percent above average in 1948 and 40 percent below average the following year. Such differences in yield, with a constant stocking rate, results in different utilization, which may in turn affect weight gains from year to year.

## Daily Gains Compared

In two comparisons, gains made by yearling replacement heifers on the Harvey Valley allotment in 1965 equaled and in 1966 exceeded the gains of their herd mates on neighboring allotments grazed season-long *(table 10).* In 1965 heifers were divided into three groups. One group grazed season-long on the Gray's Valley allotment. A second group was left in one range unit season-long, while the third group was moved to a fresh unit at midseason on Harvey Valley. In 1966 two groups of heifers were used. One group grazed in two range units (one of which was scheduled for rest) on Harvey Valley; the other group grazed season-long on the Lower Pine Creek allotment. The results shown in the table suggest that over a series of years the cattle-weight-gain balance sheet will look better for Harvey Valley than for its neighboring allotments. While two units of the Harvey Valley allotment were rested from grazing in 1965, forage quality and quantity in the remaining portion of the allotment were good enough to give weight gains equal to those of heifers grazing free choice over the entire Gray's Valley allotment. In addition, Harvey Valley heifer gains were only 12 percent less in the 1966 drought year than they were the year before, suggesting that the additional emergency feed available in rested units in Harvey Valley will improve gains over those on season-long ranges in poor forage years.

Table 10–*Starting weights and daily gains of replacement heifers on the Harvey Valley and two neighboring allotments (1965 and 1966)*

| Allotment | Grazing regime | Head | Average starting weight | Average daily gain |
|---|---|---|---|---|
| | | *No.* | *Pounds* | |
| 965: | | | | |
| Gray's Valley | Season-long | 27 | 649 ± 17[1] | 1.27 ± 0.09 |
| Harvey Valley | One unit | 28 | 642 ± 18 | 1.29 ± .08 |
| Harvey Valley | Two units | 24 | 677 ± 22 | 1.18 ± .08 |
| 966: | | | | |
| Lower Pine Creek | Season-long | 25 | 696 ± 27 | .61 ± .10* |
| Harvey Valley | Two units | 28 | 671 ± 21 | 1.09 ± .09 |

[1]Confidence interval 95 percent.
*Significantly different at 5 percent level of probability from the 1966 Harvey Valley group.

## Full- and Half-Season Gains

If year-to-year variations in gains continue about as in the past–given similar age and conditions of cattle–we can expect seasonal gains to be similar to those presented in *table 11.* The acceptability of these gains for the area around Harvey Valley has been noted earlier. Also, when regional climatic and vegetational differences are taken into account, cattle gains at Harvey Valley compare reasonably well with those from the Starkey Experimental Range in northeastern Oregon (Forest Serv. 1957, 1958; Harris and Driscoll 1954) and the Manitou Experimental Forest in Colorado (Currie 1966; Smith 1967).

Table 11–*Average starting weights and daily gains of cattle on the Harvey Valley allotment, and expected weight gain for a June 1-September 30 (120-day) season*

| Class | Head | Years of data | Average starting weight | Average daily gain | Expected seasonal gain |
|---|---|---|---|---|---|
| | *No.* | *No.* | *Pounds* | | |
| Steers | 365 | 5 | 561 ± 10.4[1] | 1.20 ± 0.03 | 145 |
| Heifers | 588 | 8 | 623 ± 9.6 | 1.12 ± .02 | 135 |
| Wet cows | 490 | 5 | 820 ± 10.8 | .66 ± .03 | 80 |
| Dry cows | 120 | 1 | 664 ± 23.2 | 1.54 ± .05 | 185 |
| Calves | 469 | 4 | 214 ± 8.1 | 1.39 ± .03 | 170 |

[1]Confidence interval 95 percent.

During the 4-month season in 1961 and 1962, yearling heifers at Harvey Valley made 73 percent of their gain before August 1 *(table 12).* They had 81 percent of their gain before August 15 during the 5-month seasons of 1962-65. It is no surprise that the rate of gain was much less during the second half of the season. Hormay and Talbot (1961) stated herbage was most nutritious just before flowering in early July. Thus, in late June and early July cattle on Harvey Valley and neighboring allotments can be expected to make their most rapid weight gains. As herbage matures, or is hit by late season frosts, gains slow to the extent that in some years weight losses occur in September and October.

*Table 12* shows a slowing of rate of gain in the latter part of the season. This has also been reported from both the Starkey Experimental Range (Forest Service 1957) and the Manitou Experimental Forest (Johnson 1953). The implications of such information for ranchers will be evident from an example.

Table 12–*Gains of replacement heifers*[1] *the first and second half of the grazing season, Harvey Valley Allotment*

| Grazing season | First half | | Second half | |
|---|---|---|---|---|
| | Days | Average daily gain (lb.) | Days | Average daily gain (lb.) |
| 1961 | 51 | 1.71 | 65 | 0.85 |
| | 51 | 1.94 | 65 | .74 |
| 1962 | 56 | 1.82 | 57 | .74 |
| | 56 | 2.00 | 57 | .24 |
| | 56 | 1.99 | 57 | .57 |
| 1963 | 68 | 1.62 | 78 | .85 |
| | 68 | 1.83 | 78 | .65 |
| 1964 | 70 | 1.68 | 74 | .08 |
| | 70 | 1.69 | 74 | .04 |
| 1965 | 73 | 1.91 | 60 | .50 |
| | 73 | 1.90 | 60 | .31 |
| Average | 63 | 1.83 | 66 | .51 |

[1]Data for each group for each year are presented because groups grazed different units or represent breed differences.

The permittee on Harvey Valley arrived each year, 1963-1965, in early June with steers weighing about 550 pounds average *(table 13).* The steers gained just over 140 pounds by an early to mid-August date when they were sold. These steers were weighed, five head at a time, on an unshrunk basis when they entered the allotment and as they went on the trucks. Also, in 1963 a group of market-type yearling heifers gained 1.9 pounds per head per day. Their average starting weight was 541 pounds, and they averaged 671 pounds 68 days later.

Table 13–*Average weights*[1] *and gains of yearling steers planned for market on August 15, Harvey Valley Allotment*

| Grazing season | Days on allotment | Starting weight | Final weight | Weight gain | Gain per day |
|---|---|---|---|---|---|
| | | *Pounds* | | | |
| 1963 | 69 | 532 | 673 | 141 | 2.04 |
| 1964 | 68 | 545 | 687 | 142 | 2.08 |
| 1965 | 75 | 586 | 728 | 142 | 1.88 |
| Average | 71 | 554 | 696 | 142 | 2.00 |

[1]Weights on an unshrunk basis.

It will be noted that both these steers and heifer gains are much higher than average seasonal gains. Keeping the animals on the range past mid-August to add additional pounds at a lower rate of gain might have resulted in a lower selling price. After midseason the permittee used the allotment for nonmarket classes such as dry cows and replacement heifers.

## Moving Cattle at Midseason

The management plan for Harvey Valley required that most of the cattle be moved at midseason. We compared gains made by animals thus moved with those of animals remaining season-long in one range unit.

Table 14–*Starting weights and daily gains of cattle grazed in one range unit and cattle grazed in two or more range units, Harvey Valley Allotment*

| Class and grazing season | Grazing treatment | | | |
|---|---|---|---|---|
| | One range unit | | Two or more range units | |
| | Average starting weight | Average daily gain | Average starting weight | Average daily gain |
| | *Pounds* | | *Pounds* | |
| Steers: | | | | |
| 1958 | 538 | 1.21 | 549 | 1.17 |
| Heifers: | | | | |
| 1957 | 446 | 1.41 | 471 | 1.20* |
| 1959 | 514 | .86 | 547 | .83 |
| 1961 | 528 | 1.22 | 529 | 1.27 |
| 1965 | 642 | 1.28 | 677 | 1.18 |
| Wet Cows: | | | | |
| 1956 | 721 | .86 | 735 | .71* |
| 1957 | 839 | .73 | 903 | .53 |
| 1958 | 894 | .55 | 924 | .67 |
| 1959 | 803 | .38 | 796 | .34 |
| Dry Cows: | | | | |
| 1956 | 664 | 1.56 | 664 | 1.53 |
| Calves: | | | | |
| 1956 | 145 | 1.57 | 144 | 1.46* |
| 1957 | 257 | 1.52 | 292 | 1.44 |
| 1958 | 236 | 1.39 | 269 | 1.22* |
| 1959 | 258 | 1.35 | 237 | 1.39 |

*Statistically significant at 5 percent level of probability.

In four out of 14 comparisons cattle moved between range units gained significantly less than those not moved *(table 14).* In no case did cattle grazed season-long in one range unit gain significantly less than those that were moved. Assuming this pattern continues at Harvey Valley about one-third of the time, 7 to 20 percent greater gains can be expected for cattle not moved.

Rigid rotation of cattle to fresh units is now considered unnecessary. Rather, Hormay (1970) recommends opening gates at the appropriate times and letting the cattle drift into the fresh units. Doing so will eliminate weight loss from forced moving and also the expense of gathering at midseason.

## Livestock Production and Value Per Acre

The pounds of gain per usable acre *(table 15),* produced on the Harvey Valley allotment were estimated using the average daily gain *(table 11)* for

each class of cattle. Except for calves, which were included with wet cows, the assumption was made that only one class of cattle was on the allotment and used its entire grazing capacity. Calves gained 3.8 pounds per acre of the 5.6 pounds for cows and calves *(table 15).*

Table 15–*Estimated allotment capacity and livestock production by class of cattle, Harvey Valley Allotment*

| Class of cattle | Animal unit rating | Animal days to use capacity[1] | Estimated pounds gain per acre[2] |
|---|---|---|---|
| Cows and calves[3] | 1.25 | 49,440 | 5.6 |
| Steers | .75 | 82,400 | 5.5 |
| Heifers | .80 | 77,250 | 4.8 |
| Dry cows | .90 | 68,667 | 5.9 |

[1]Capacity of the Harvey Valley allotment was 61,800 A.U.D.

[2]17,956 acres were usable for grazing on the Harvey Valley allotment in 1960.

[3]Cows = 1.00 A.U.; calves = .25 A.U.

On the animal unit basis the value produced for cows and calves–at 15 cents and 25 cents per pound for cows and calves respectively–was $1.23 per acre. The largest part, 96 cents, came from the calf gains. The value of the gain for steers–at 24 cents per pound–was $1.32 per acre. For heifers, at the same price per pound, it was $1.15. Under these conditions (dry cows excluded) there appears to be some advantage to grazing steers rather than other classes of cattle at Harvey Valley.

## *Discussion*

We consider one of the primary advantages of rest-rotation over season-long grazing to be the availability of forage in rested units. That having this reserve of forage may improve weight gains in poor forage years was indicated by the greater gains made by yearling heifers on Harvey Valley versus the gains of those on the Lower Pine Creek allotment in 1966. Also, cattle were removed well before the end of the grazing season from some neighboring season-long allotments (because of lack of forage) during the drought years of 1959-61. The Harvey Valley permittee never took his cattle home early. Rather, the cattle were moved to units scheduled for rest during these and other poor forage years.

A second advantage is that rest-rotation provides for cultural as well as ecological improvement. Standard Forest Service practice would require a period of nonuse following cultural improvement work such as seeding or sagebrush control. At Harvey Valley, such work could be fitted into the rest-rotation pattern without nonuse periods being required.

Rest-rotation grazing at Harvey Valley has produced acceptable cattle weight gains and has probably resulted in greater beef production than would have been achieved under continued season-long grazing. At the same time, range conditions have improved relative to neighboring allotments grazed season-long. In view of these achievements, we recommended a 10-percent increase in the permitted animal unit months of grazing for the Harvey Valley allotment. This increase was granted in 1967.

# ECONOMIC CONSIDERATIONS

Rest-rotation grazing produced better relative range conditions and acceptable cattle weight gains, but the question remains: Was the prescription for Harvey Valley economically practical? The following discussion aims to answer this question from the standpoints of the Forest Service and of the livestock permittee.

The test at Harvey Valley, the first Forest Service allotment to be placed under rest-rotation grazing, was intended to demonstrate the grazing principles developed by Hormay and Talbot (1961). Therefore, it included some practices, such as the use of five-wire fences and strict control of cattle, which are usually not in present programs. Hence, the costs at Harvey Valley may not be representative of costs of programs elsewhere. The figures used in this analysis are based on costs that were incurred. An economic analysis comparing rest-rotation and season-long grazing was not planned. Therefore since no actual records were available, Forest Service and permittee costs and returns for a season-long program were estimated.

To protect resources it is sometimes necessary to reduce grazing use on an allotment. A rancher may, however, be given the choice of taking a cut or of accepting a program of intensive management, such as rest-rotation grazing. Avoiding reductions can benefit both ranchers and ranch communities (U.S. Forest Service 1972). The last reduction at Harvey Valley was in 1948, and no further reduction was anticipated at the time rest-rotation grazing was being planned.

Had season-long grazing been continued at Harvey Valley, some additional reduction in permitted use would probably have been necessary eventually to gain improvement in relative condition—even with intensive cultural treatment and moderate stocking. McLean and Tisdale (1972) estimated that 20 to 40 years of complete rest are required for overgrazed ranges in southern British Columbia to recover to a productive condition. Therefore, the fact that improvement without further reductions occurred must be considered a benefit of rest-rotation grazing. But moderate season-long grazing also can benefit range condition, through controlling less desirable plants and covering seed, and cultural improvements would likely delay the time when a reduction was needed. We could not say with certainty how great an additional reduction would have been necessary nor when or for how long it would have had to be in effect. Therefore, we could not assign this benefit a monetary value.

Increases in permitted use, which result from improved range condition, are also positive benefits of rest-rotation. Although the season of use was extended 1 month in 1963, the permitted use (2060 A.U.M.'s) was held constant. The increase given in 1967 is, however, accounted for in our consideration of permittee costs.

Emergency forage available in rested units is a primary advantage of rest-rotation grazing. We know cattle were sometimes removed from neighboring allotments, but not from Harvey Valley, because of a lack of forage; and we know that in 1 drought year heifers on Harvey Valley gained more than those on an allotment grazed season-long. But we could not place a monetary value on the emergency forage. We lacked sound documentation of the facts regarding other permittees taking their cattle home early. Furthermore, 1 year's results is not enough to justify using a value for extra weight gained during drought.

Another advantage given for rest-rotation grazing is that cultural improvements can be applied without requiring periods of nonuse. Nonuse was not required at Harvey Valley, and therefore not recorded. Consequently, we could not place a monetary value on this advantage. We did, however, estimate the amount of fence required to protect the seedings had Harvey Valley remained under season-long grazing. These fence costs were included in calculating costs of season-long grazing.

Returns from range improvement such as better plant vigor and species composition, more litter cover and less bare soil, more cover of primary value plants, and more rapid absorption of water cannot be assigned realistic dollar values. Therefore, they cannot be included in a cost/return analysis.

The Harvey Valley permittee estimated that his cattle lost 50 pounds per head during late September and October. Hormay and Talbot (1961) reported that weight losses can be expected starting about October 1. The permittee ascribed 30 pounds of the weight loss to dry forage lacking protein and 20 pounds to the "forced feeding" (periods of full grazing) used in the rest-rotation program at Harvey Valley. However, we have no data to support the contention of added weight loss due to "forced feeding." Also, our data show that rest-rotation has produced acceptable cattle weight gains. Because of differences in opinion, we did not include a value for the 20 pounds per head in figuring the costs of rest-rotation.

In addition, the permittee gave $658 as the cost for extra riding under rest-rotation grazing. This is 78 percent of his regular costs for riding with season-long grazing. Normally when an allotment is crossfenced, thereby restricting the movements of cattle, we consider that the amount of riding required is reduced rather than increased. But based upon our knowledge of the amount of riding actually done—not what should be done—on season-long allotments in our area, we concluded that the increased riding charged to rest-rotation was justified. Therefore, extra riding was included as a cost to the permittee.

## Cost for Forest Service

### Methods of Analysis

The Forest Service received no monetary benefits for rest-rotation grazing (other than regular grazing fees, which we assumed would have also been received under season-long grazing) that we could include in our analysis. On a strictly monetary cost/return basis, rest-rotation grazing at Harvey Valley did not pay its way through 1965—the costs simply exceeded the dollar returns. Therefore, we decided to compare costs of rest-rotation with costs of season-long grazing at a similar intensity of cultural development and to determine what would have been required to pay the added Forest Service costs incurred by rest-rotation. We assumed that no return on the value of the Forest Service grazing land was required.

The original study plan for Harvey Valley called for cultural range improvement practices, development of additional water, additional fencing, and cattle handling facilities. Not all of the expenditures were chargeable to Harvey Valley alone, or to rest-rotation grazing specifically. Because of this, a break-

Table 16—*National Forest System budget expenditures related to the Harvey Valley program, 1951-1965 inclusive*

| Expenditures | Costs chargeable to | | Estimated costs under season-long grazing |
|---|---|---|---|
| | Associated costs | Rest-rotation grazing | |
| Improvements and treatments | | | |
| Seeding (497 acres) | — | $7,075 | $7,075 |
| Brush control (3,655 acres) | — | 13,108 | 13,108 |
| Grasshopper control (100 acres) | — | 500 | 500 |
| Drainage improvement (300 acres) | – | 600 | 600 |
| Erosion control (1 mile) | — | 130 | 130 |
| Boundary fence (11.54 miles) | $5,695 | 5,695 | 5,695 |
| Interior fence (16.17 miles) | 3,000 | 13,670 | |
| Fence for seedings (7.8 miles) | | – | 7,800 |
| Metal gates (11) | 120 | 364 | 120 |
| Cattleguards (12) | 12,057 | 332 | 175 |
| Spring development (1) | – | 1,200 | – |
| Extra troughs (2) | — | 881 | — |
| Water pits (11) | — | 1,669 | 1,269 |
| Corral and scales | 5,269 | — | — |
| Other Costs | | | |
| Maintenance of improvements | 4,892 | 13,328 | 6,785 |
| Planning costs | 2,260 | 3,909 | 2,478 |
| Range rider costs | 7,680 | – | – |
| Total | $40,973 | $62,461 | $45,735 |

down of actual costs *(table 16)* was necessary, as follows: (a) costs associated with the program but rightly charged to research requirements, demonstration activities, adjacent allotments, and other uses (these costs were not included in the analysis); (b) costs incurred to develop and manage the allotment under rest-rotation grazing; and (c) costs of standard Forest Service grazing management practices, which we estimated would have been incurred had the allotment been equally developed but remained under season-long grazing. Costs on record for improvements made before 1951 were broken down in the same way, and those applicable were included in the analysis.

The decisions as to allocation of costs in the three categories were reached through discussions with the District Ranger, Fred J. Alberico. Estimates of the life expectancies of improvements and cultural treatments used to calculate depreciated values were agreed upon with him and Philip B. Lord, formerly grazing staff officer for the Lassen National Forest. The Forest staff provided cost figures for the maintenance of the improvements and treatments and all original investment values. The depreciated values at the start of 1951 were used as the values for investments made before that year.

We treated the costs for each year as the sum of the costs for improvements and treatments, planning, and maintenance for that year. The costs for each year which could not be repaid were accumulated to determine the total investment cost for the Forest Service.

Total planning costs related to the Harvey Valley program ($6,169—*table 16*) amounted to 8.6 percent of the total cost of improvements and treatments for 1951 to 1965 inclusive. Thus, planning costs for each year were estimated by multiplying total costs for improvements and treatments by 8.6 percent. These estimated planning costs were accepted as reasonable by the people involved in the planning activities.

Costs through 1965 were calculated four ways *(table 17)*. The basic amount method used the basic dollar amounts summed for the 15-year period. Unpaid costs at the end of 1965 were simply determined by subtracting the net grazing fee paid during the period based on 2060 A.U.M.'s. This method of cost calculation most closely represents the bookkeeping procedures of the Forest Service.

Net grazing fees—the total fees the permittee paid less 25 percent—were used because 25 percent of Forest Service revenues must be returned to the county regardless of costs. In effect, this is an off-the-top cost to the Forest Service paid in lieu of taxes.

The add-on loan method follows the principle of add-on loans at an interest rate of 5 percent compounded annually. Unless stated otherwise, all in-

Table 17 *Actual costs and costs for 15- and 30-year pay off through 1965 for rest-rotation and season-long grazing at Harvey Valley*

| Method of calculating costs | Costs under rest-rotation grazing | | | | Extra costs[2] | Estimated costs under season-long grazing | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total | Payments | 1965 unpaid costs | Average annual[1] | | Total | Payments | 1965 unpaid costs | Average annual |
| | *Dollars* | | | | *Percent* | *Dollars* | | | |
| Basic amount | 70,029 | 13,720 | 56,309 | 4,668 | 26 | 55,424 | 13,720 | 41,704 | 3,695 |
| Add-on loan | 115,637 | 13,720 | 101,917 | 7,709 | 28 | 90,672 | 13,720 | 76,952 | 6,045 |
| 15-year pay off | 93,001 | 93,001 | — | 6,200 | 26 | 73,815 | 73,815 | — | 4,921 |
| 30-year pay off | 104,116 | 52,892 | 51,224 | 6,941 | 26 | 82,763 | 42,454 | 40,309 | 5,518 |

[1] Based on total costs.

[2] Percent by which average annual costs of rest-rotation exceed average annual costs of season-long grazing; i.e., ($4,668 - $3,695/$3,695) x 100 = 26 percent.

terest costs were calculated as if all funds were loaned on the first day of the year. The value of the add-on loan was calculated as follows: The total cost for year one (1951), plus an interest charge on that total cost, less the net grazing fees paid in 1951 is equal to the value of the add-on loan on the last day of year one. The value of the add-on loan on the last day of year one, plus the total cost for year two (1952), plus an interest charge on both the previous amounts, less the net grazing fees paid in 1952 is equal to the value of the add-on loan for the last day of year two (1952). The procedure was repeated through 1965. The value of the add-on loan remaining at the end of 1965 was thus the unpaid cost, plus the total interest charges through 1965. These calculations assumed that grazing fees would not be available for use until the end of the year.

The other two ways of calculating costs were as follows: For a commercial type operation to retire the final value of the add-on loan, the required annual revenues were calculated on the basis of both a 15-year pay off period (ending in 1965), and a 30-year pay off period (ending in 1980); these are hereafter referred to as the 15-year and 30-year pay off methods, respectively. In place of the net grazing fees actually paid, we used the annual revenue required to amortize the face amount of the loan outstanding by the end of 1965 and 1980. For the 15-year pay off, the payment required for year one was figured by using the amortization factor for 15 years and for year two, the amortization factor for 14 years, etc. The total payments required, through 1965, to eliminate all unpaid costs at the end of the 15-year period is the total cost of the program *(table 17).* Total cost for the 30-year pay off method is the sum of the required payments through 1965 and the unpaid costs remaining at the end of 1965. Because of the method of amortizing costs and because cost incurred varied from year to year, the required annual revenues were not the same for each year.

## Results

Regardless of which of the four methods of calculating costs is used, average annual costs for rest-rotation grazing at Harvey Valley through 1965 were greater than they would have been had the allotment remained under season-long grazing, with improvements and treatments carried on at the same intensity. The extra costs of rest-rotation amounted to 26 percent of the costs for season-long grazing for all methods, except for the add-on loan method. And for that method the extra cost was 28 percent of the cost for season-long grazing.

More will have to be paid in the future to cover unpaid costs, regardless of the grazing program, than would have been necessary had grazing fee income originally been geared for pay off. Unpaid costs *(table 17)* were naturally zero for the 15-year pay off method. For both rest-rotation and season-long grazing, the unpaid costs for the 30-year pay off method were 49 percent of the total cost. But unpaid costs for the add-on loan method were 88 and 85 percent and for the basic amount method, 80 and 75 percent of the total costs for rest-rotation and season-long grazing respectively.

In the discussion below, care should be taken to distinguish between grazing fee per A.U.M. and net grazing fee per A.U.M. For example, the average grazing fee per A.U.M. paid from 1951 to 1965 inclusive at Harvey Valley was 59 cents. After paying the county 25 percent of grazing fees in lieu of taxes, the average net grazing fee per A.U.M was 44 cents.

Two types of comment based on *table 18* should be included. The first is based on the differences be-

Table 18—*Unpaid costs through 1965, expressed as costs per A.U.M.*[1] *for basic and add-on loan amounts, and the net grazing fees required to break even with a 15- and a 30-year pay off period for rest-rotation and season-long grazing at Harvey Valley*

| Method of calculation | Rest-rotation grazing | | | Season-long grazing | | |
|---|---|---|---|---|---|---|
| | Unpaid cost per AUM[2] | Fees required to break even | | Unpaid cost per AUM | Fees required to break even | |
| | | 15-year[3] | 30-year | | 15-year | 30-year |
| Basic amount | $1.83 | 2.27 | [4]1.13 | 1.35 | 1.79 | 0.90 |
| Add-on loan | 3.30 | 3.01 | [5]1.71 | 2.49 | 2.39 | 1.37 |

[1] Total A.U.M.'s of grazing, 1951–65 inclusive (based on a 2,060-A.U.M. capacity) were 30,900.
[2] Unpaid costs in 1965 *(table 17)*/30,900 A.U.M. = unpaid costs per A.U.M.
[3] Total costs *(table 17)*/30,900 A.U.M. = fees required to break even at end of 1965, eg., $70,029/30,900 = $2.27 and 93,001/30,900 = $3.01.
[4] Total costs *(table 17)*/61,800 A.U.M. = fees required to break even at end of 1980, eg., $70,029/61,800 = $1.13.
[5] Payments through 1965 *(table 17)*/30,900 A.U.M. = fees required to break even at end of 1980, eg., $52,892/30,900 = $1.71.

tween the costs per A.U.M. for rest-rotation and season-long grazing. The second involves the level of net grazing fees required if the Forest Service were to incur no unpaid costs at Harvey Valley.

Rest-rotation at Harvey Valley cost more per A.U.M. than season-long grazing would have, at least during the period covered by this analysis. Using the basic amount method *(table 18),* net grazing fees per A.U.M. for rest-rotation would have had to be 48 cents ($2.27-$1.79) greater than for season-long grazing for unpaid costs under rest-rotation to be equal to those under season-long grazing in 1965. For the unpaid costs to be equal in 1980, net grazing fees per A.U.M. for rest-rotation would had to have been 23 cents ($1.13-$.90) greater than for season-long grazing. Using the add-on loan method, net grazing fees per A.U.M. for rest-rotation would have had to be 62 cents ($3.01-$2.39) greater than for season-long grazing for unpaid costs under rest-rotation to be equal to unpaid costs under season-long grazing in 1965. For the unpaid costs to be equal in 1980, net grazing fees per A.U.M. for rest-rotation would have had to be 34 cents ($1.71-$1.37) greater than for season-long grazing.

If no unpaid costs are to be incurred by the Forest Service, the break even net grazing fees *(table 18)* represent the kind of net fees that must be considered. For example, assume that the basic amount method (which assumes that the Forest Service need not consider interest charges on the capital it uses) is considered the appropriate method and that all costs incurred should have been paid off by 1965. In that case, the net grazing fee should have been $2.27 per A.U.M. The grazing fee charged the permittee would be $3.03 per A.U.M. This amount is considerably higher than the 59 cents per A.U.M. actually charged. However, using the same assumptions for season-long grazing, the net grazing fee should have been $1.79 per A.U.M., and the permittee should have been charged $2.39 per A.U.M. Obviously, not all of the unpaid costs under rest-rotation at Harvey Valley can be attributed solely to rest-rotation grazing. Part of these unpaid costs are the result of a grazing fee structure that would have failed to cover even the costs of normal Forest Service operations.

It seems clear, using 1951-65 grazing fee schedules, that increases in permitted use can never cover the costs to the Forest Service for rest-rotation grazing at Harvey Valley. Using the basic amount method and a 100 percent increase in grazing capacity, it would take 31 more years at 1951-65 fee levels to pay off the unpaid costs remaining at the end of 1965. This conclusion assumes that the Forest Service incurs no cost after 1965. But fences and other improvements must be maintained or replaced over the years. Therefore, higher grazing fees must be charged for grazing the Harvey Valley allotment under rest-rotation grazing, if the bill is to be paid from grazing fees.

Using the basic amount method and the 30-year pay off period (the most favorable comparison of rest-rotation with season-long grazing in *table 18*) the net grazing fee under rest-rotation at Harvey Valley would have had to be 23 cents ($1.13-.90) greater than for season-long grazing. To provide the county

its 25 percent share of the grazing fees collected, the grazing fee paid by the permittee would have had to be 31 cents per A.U.M. greater than paid under season-long grazing. Had firm values for benefits from range condition improvement been available, however, the extra fee required to pay the cost of rest-rotation grazing would have been lower.

## Cost for Livestock Permittee

### Method of Analysis

The permittee did not accrue any added monetary benefits from rest-rotation grazing until after 1965. He continued to receive the returns from cattle weight gains that we estimated would have been received under season-long grazing. Therefore, during the period from 1954, when rest-rotation became fully operational, through 1965, the extra costs the permittee incurred were not covered by added income from rest-rotation grazing. Costs not offset by added income must be considered an investment by the permittee. Increased benefits after 1965 and those through 1965 to which we could assign no monetary value must be considered by the permittee in deciding if his investment was justified.

For the purposes of this report, however, permittee costs were analyzed on the assumption that the permittee must cover all his costs and pay interest on all money used each year. During the study period, the permittee paid 6.5 percent interest on the funds used for this part of his operation. This figure was used in computing all interest charges. To simplify calculations, we assumed that interest would be charged for an entire year. Although this procedure tends to overestimate interest costs, they would be reduced only slightly by a more detailed breakdown of actual time when interest was paid.

Permittee costs were separated into three parts: (a) regular costs to operate the allotment without rest-rotation; (b) extra costs incurred because of rest-rotation grazing; and (c) extra costs incurred because of research activities. The breakdown of costs was discussed with and agreed upon by the permittee. No interest was charged to what the permittee had invested in land, cattle, and equipment.

### Results

Yearly costs to the permittee averaged $10,168 *(table 19)*. Of this amount, regular costs, which would be incurred under season-long grazing, accounted for 89.1 percent. His costs for extra maintenance and riding, chargeable to rest-rotation, accounted for 8.8 percent. The remaining 2.1 percent was the cost of aiding our research (these costs were not included in the analysis).

Table 19–*Average yearly costs to permittee for rest-rotation grazing at Harvey Valley–1954–1965*

| Expenditure | Average yearly net cost *(dollars)* | Interest charged at 6.5 percent *(dollars)* | Average yearly cost *(dollars)* | Total cost *(percent)* |
|---|---|---|---|---|
| **Regular costs** | | | | |
| Maintenance | 208 | 14 | 222 | 2.2 |
| Riding | 880 | 57 | 937 | 9.2 |
| Grazing fees | 1,236 | 80 | 1,316 | 12.9 |
| Livestock overhead | 4,120 | 268 | 4,388 | 43.2 |
| Livestock transportation | 2,060 | 134 | 2,194 | 21.6 |
| Total | 8,504 | 553 | 9,057 | 89.1 |
| **Added costs because of rest-rotation** | | | | |
| Maintenance | 185 | 12 | 197 | 1.9 |
| Riding | 658 | 43 | 701 | 6.9 |
| Total | 843 | 55 | 898 | 8.8 |
| **Added costs because of research** | | | | |
| Riding | 130 | 8 | 138 | 1.4 |
| Weighing cattle | 70 | 5 | 75 | .7 |
| Total | 200 | 13 | 213 | 2.1 |
| Grand total | 9,547 | 621 | 10,168 | 100.0 |

Included under "regular costs" were grazing fees, overhead, and transportation. Potentially, these costs could vary if the grazing capacity were to change. An increase in the total grazing fees resulting from an increase in permitted numbers as the result of a rest-rotation program, for example, would be chargeable to rest-rotation grazing rather than to regular costs.

With a 515-head permit, what return per head was necessary for the permittee to cover his costs? To pay all annual costs, excluding those attributable to research activities, the return per head from Harvey Valley would have to be $19.33 or $4.83 per animal-unit month. The return per head needed to pay his costs, had the allotment been under season-long grazing, was $17.59. Therefore, his extra costs due directly to rest-rotation grazing was $1.74 per head. Results from our studies show that no additional return was generated up to 1965. Therefore, it cost the permittee 9.4 percent more annually to operate under rest-rotation grazing.

The permittee had to be willing and able to accept uch extra costs if a plan of rest-rotation was to be uccessful. His extra costs should, therefore, be conidered as an investment in range health aimed at ither preventing future cuts in permitted use or proiding increased future income, rather than simply a ost. Since no grazing cuts were planned at Harvey 'alley, the question becomes: "Was the permittee's nvestment at Harvey Valley economically sound?"

The permittee's extra annual costs, not including nterest charges, for rest-rotation grazing were $843. he permittee could have invested this $843 each ear. This amount invested annually at 6.5 percent, ompounded quarterly, would be worth $17,715 at he end of 13 years (1954-66 inclusive). That period s used here because the recommendation for a 10 ercent increase was not implemented until after the 966 grazing season. Therefore, by then, the permitee had, in effect, invested $17,715 in rest-rotation razing at Harvey Valley.

What sort of increased income would be required o pay off this investment of $17,715? To return this investment in 20 years at 6.5 percent interest, the permittee's increased income from increased permitted use would have to be $1,608 per year. This income could be generated by the permittee because he could use the increased permitted use resulting from rest-rotation to (a) substitute the Forest Service grazing for more expensive feed and thereby decrease his costs or (b) increase the size of his herd and with this increase, increase his net income.

After 1966, the permitted use was increased by 206 A.U.M.'s. Additional livestock could be added or the regular livestock could be grazed for a longer period. The permittee selected the second alternative. We were not able to obtain information on the costs to the permittee of alternative sources of feed. If a Forest Service grazing fee of 59 cents per A.U.M. (the average paid between 1951 and 1965) is used, the feed alternative to be replaced by the increased permitted use of 206 A.U.M. would have to cost $1,608/(206 A.U.M.) + 59¢ = $8.40 per A.U.M. before the investment in rest-rotation would be at the break even point. However, feed may not be available on a

Table 20—*Increases in permitted use required if permittee's investment is to break even within 20 years (1985)*

| Item | No increase in overhead and transportation costs | | | | Proportionate increases in overhead and transportation costs | | | |
|---|---|---|---|---|---|---|---|---|
| | Average value per pound for all cattle in herd *(cents)* . . . | | | | Average value per pound for all cattle in herd *(cents)* . . . | | | |
| | 20 | 25 | 30 | 35 | 20 | 25 | 30 | 35 |
| | *Dollars* | | | | | | | |
| Increased value per A.U.M. | 10.00 | 12.50 | 15.00 | 17.50 | 10.00 | 12.50 | 15.00 | 17.50 |
| Grazing cost[1] | .64 | .64 | .64 | .64 | .64 | .64 | .64 | .64 |
| Interest cost[2] | 1.08 | 1.35 | 1.63 | 1.90 | 1.08 | 1.35 | 1.63 | 1.90 |
| Overhead and transportation costs[3] | – | – | – | – | 3.20 | 3.20 | 3.20 | 3.20 |
| Total increase in cost | 1.72 | 1.99 | 2.27 | 2.54 | 4.92 | 5.19 | 5.47 | 5.74 |
| Gross profit per A.U.M. | 8.28 | 10.51 | 12.73 | 14.96 | 5.08 | 7.31 | 9.53 | 11.76 |
| Required A.U.M. increase in permitted use[4] | 303 | 238 | 197 | 168 | 493 | 343 | 263 | 213 |

[1] Grazing fee of $.64 included interest charge but fees do not reflect the normal adjustment that takes place as cattle prices vary.
[2] (1000 lbs.) (price per lb.) (.065)/12 = interest charge per A.U.M. *(table 19).*
[3] ($6,583)/(2,060 A.U.M.) = overhead and transportation cost.
[4] Cost of continuing rest-rotation $897.80 per year (see *table 19*) $1,608 + $897.80 = $2,505.80 = total cost per year except for costs presented above ($2,505.80)/(gross profit per A.U.M.) = required increase in permitted use.

rental basis. The permittee may face the choice of either depleting reserve feed on his own range land or decreasing herd size unless permitted use can be increased. If, for example, grazing were available at $3.60 per A.U.M., rest-rotation would have to result in an increase in permitted use of 534 A.U.M. or an increase in permitted use of 26 percent before the investment in rest-rotation would be at the break-even point.

If the increase in permitted use were used to expand herd size, the impact on both permittee costs and revenues must be considered. The permittee's herd averaged about 50 pounds of gain for each A.U.M. of grazing *(table 11). Table 20* presents the increase in permitted use required if the permittee is to increase his profits by $1,608 per year for alternative combinations of prices and costs.

By inspecting the last row of *table 20,* it can be seen that the permittee must expect a favorable combination of both prices and costs for his investment in rest-rotation to pay off. If there were a permanent increase in permitted grazing of 206 A.U.M and this resulted in an expanded herd size, the gross profit per added A.U.M. would have to be at least $12.16.

It is not possible to state categorically whether a permittee's investment in rest-rotation grazing will pay off. But at Harvey Valley, the permittee's investment could be economically sound–given a favorable price, cost combination after 1966. The questionable nature of a permittee's investment in rest-rotation may no longer exist where cuts in use are anticipated if the present grazing program is continued and he would suffer a loss in income, and where installation of a rest-rotation program would nullify the cuts.

## Discussion

A house properly maintained will last for many years, but uncared for it will soon deteriorate. In the end, it may cost the owner less to properly maintain the house than to permit it to deteriorate and then decide to restore it. So with our range resources. For many rangelands, including Harvey Valley, we are faced with a restoration rather than a maintenance problem. Man's economic time scale is not the same as nature's ecologic time scale. And the public must expect restoration to cost more than maintenance of range health.

As shown above, for both the permittee and the Forest Service, monetary costs exceeded monetary returns during the first years of rest-rotation grazing on the Harvey Valley allotment. However, considered as an investment, the extra costs incurred by the permittee during 13 years–given a favorable combination of both prices and costs–can be recovered as a result of improved range condition and greater grazing capacity.

Monetary returns from grazing, i.e., grazing fees and cattle sales, are important, but long-term returns resulting from improvement of the resource (including esthetic values) must not be ignored. On 17,956 acres of usable range, the added cost to the Forest Service of rest-rotation grazing was about 9 cents per acre per year, using the add-on loan method. For this the public received the return of a better range condition on Harvey Valley as compared to nearby allotments and, with the resulting increase in permitted use, an increase in payments to the county.

Still, the bill for rest-rotation grazing at Harvey Valley will eventually have to be paid. But who should pay it? The rancher? The "public" through the Forest Service? Or someone else? The rancher earns income from the resource–and so perhaps he should pay. But the "public" demands that the Forest Service improve the range environment–and so perhaps the "public" should pay. Or perhaps ranchers on season-long allotments should pay for not participating in grazing management practices which would improve the range environment.

One point is, however, in order. On the basis of the 30-year pay off method for calculating the cost of rest-rotation grazing *(table 18),* the public in effect has subsidized grazing to the amount of $1.27 ($1.71-.44) per A.U.M. Had Harvey Valley remained under season-long grazing, however, the subsidy would still have been 93 cents ($1.37-.44) per A.U.M.

Rest-rotation grazing has improved the range environment at Harvey Valley. The magnitude of this improvement may well justify the additional 34-cent subsidy per A.U.M. But whether it does and as to who should pay the bill for rest-rotation grazing–these are issues that must be settled by those responsible for making social, political, and administrative decisions.

# SUMMARY

Ratliff, Raymond D., Jack N. Reppert, and Richard J. McConnen
1972. **Rest-rotation grazing at Harvey Valley. . .range health, cattle gains, costs.** Berkeley, Calif., Pacific SW. Forest & Range Exp. Sta. 24 p., illus. (USDA Forest Serv. Res. Paper PSW-77)

*Oxford:* 268.6(794): 187x666: 181.42: 651.7.
*Retrieval Terms:* range management; rest-rotation grazing; environmental impact; economic evaluation; Harvey Valley, California.

Since 1954, a trial of rest-rotation grazing has been underway on the Harvey Valley allotment on the Lassen National Forest, northeastern California. The grazing prescription calls for a 5-year rotation of full use, full rest, early-season rest with late-season use, full rest, and early-season use with late-season rest. Nearby allotments have continued to be grazed season-long.

This paper reports an evaluation of progress observed at Harvey Valley to 1966. It summarizes findings in comparative range health and apparent condition trends; in cattle weight gains, and in cost/return analysis from the standpoint of both the Forest Service, which owns the land, and the permittee, whose livestock are grazing on the land.

Studies of relative range conditions on Harvey Valley and nearby allotments were begun 10 years after the start of rest-rotation grazing. Although the response to the grazing program was undoubtedly slowed by drought, results showed that range condition had improved and apparent condition trend was upward on Harvey Valley. Therefore, compared with season-long grazing, rest-rotation grazing is ecologically sound. At Harvey Valley, compared to nearby allotments, there was (1) improved vigor of the key forage species, Idaho fescue; (2) greater basal cover of the better plants; (3) a higher successional stage as indicated by a better species composition; (4) more grass seedlings; (5) more litter cover and less exposed soil; (6) greater herbage yield; and (7) less soil compaction, with faster water absorption.

Cattle weight gains at Harvey Valley were as good as could be expected in the vicinity. From 1954 through 1966, individual cattle gains neither increased nor decreased on Harvey Valley. In some years, cattle that were moved from one to another of the five range units at midseason made lower gains than cattle allowed to graze one of the range units for the entire season.

In one of two comparisons with nearby allotments, heifers on Harvey Valley gained one-half pound per day more than those grazed season-long. In the other test, however, gains were the same. These results indicate that over a series of years, cattle gains would prove better under rest-rotation grazing.

Other studies showed that a rancher can get a 2-pound gain per day from yearling stockers the first half of the grazing season. Keeping them past mid-August adds pounds but at a much lower rate.

During the first years at Harvey Valley, the monetary costs of rest-rotation grazing exceeded the monetary returns to both the Forest Service and the livestock permittee. There were, however, several benefits and some costs upon which we could place no firm monetary values. The analyses, therefore, dealt only with those costs and returns for which we could fix firm values.

A five-unit rest-rotation prescription with a given level of cultural improvement cost the Forest Service 28 percent more (by the add-on loan method of calculation) than season-long grazing on the same area with the same level of cultural improvement would have cost. The unpaid costs for rest-rotation grazing at Harvey Valley at the end of 1965 amounted to 88 percent of the total costs from 1951 through 1965. For an even break, the net grazing fee per A.U.M. would have had to be 62 cents more for a 15-year pay off or 34 cents more for a 30-year pay off than what was charged for season-long grazing. But just to have had a break-even arrangement with season-long grazing, either $1.95 (for 15-year pay off) or $0.93 (for 30-year pay off) more than actual net grazing fees (44 cents/A.U.M) would have been required. And it is unlikely that the relative condition would have improved.

Rest-rotation cost the livestock permittee 9 percent more annually than season-long grazing would have. But considered as an investment, with the 10 percent increase and a favorable combination of both prices and costs, his extra costs can be recovered. Therefore, given a gross profit of $12.16 per A.U.M. the permittee's investment would be economcally sound.

Rest-rotation grazing is primarily a procedure for restoring range health and restoration can be expected to cost more than maintenance. Rest-rotation grazing is not a panacea for all ranges and all range

problems. Now, however, it is the best approach to grazing management available for many western ranges.

At Harvey Valley, rest-rotation grazing is doing much of what was expected. But one should not expect that just over one decade of rest-rotation would restore the loss in range condition and grazing capacity that occurred from 1870 to 1948. With the improvement in relative range condition which has occurred, we can expect greater and more rapid improvement in the future.

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Forest and Range
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# SPECIFIC GRAVITY VARIATION IN ROBUSTA EUCALYPTUS grown in Hawaii

Roger G. Skolmen

CLEMSON UNIVERSITY
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## The Author

**ROGER G. SKOLMEN** is on the staff of the Station's Institute of Pacific Islands Forestry, with headquarters in Honolulu, Hawaii, where he has been investigating the uses, properties, and processing of forest products. Native of San Francisco, he holds B.S. (1958) and M.S. (1959) degrees in forestry from the University of California, Berkeley.

Robusta eucalyptus *(Eucalyptus robusta* Sm.*)* is an important timber species in Hawaii. The density, or specific gravity, of its wood has been measured in conjunction with standard physical and mechanical property tests (Gerhards 1963; Youngs 1960). It has also been measured as part of an exploratory investigation of brittleheart (brash wood near the pith) in the species (Skolmen and Gerhards 1964). These tests, as well as the general observations of most people who have worked with it, indicate that the wood varies widely in density, not only from one tree to another, but also in wood from one tree and even from one part of a board to another. Because most other properties of the wood are closely related to density, this variation causes many manufacturing problems.

This paper reports data on specific gravity gathered as part of a larger study to determine the extent of brittleheart in robusta. Because brittleheart was suspected to vary widely in volume from tree to tree, a relatively large sample of wood from 50 trees was gathered. This large sample made possible an intensive investigation of specific gravity variation.

## PROCEDURE

Ten stands of robusta eucalyptus growing along the northeast coast of the island of Hawaii were selected for sampling. The stands represented the widest available range of age, elevation, and rainfall differences. Five trees at least 11 inches diameter breast height (d.b.h.) and containing at least one 16-foot log were randomly selected from each stand. Cross sections 1 foot long were cut from the large end of each 16-foot log in each tree and from just above the small end of the uppermost log. In some trees the uppermost log was only 8 or 12 feet long rather than 16 feet *(fig. 1)*. In the forest, 2-inch thick flitches with centered pith were sawn from the cross sections. In the shop, the flitches were sawn in line with the pith into 1-1/8 by 1-1/8-inch sticks, which, after air-drying, were further manufactured into 2- by 2-by 28-centimeter toughness test sticks. Each stick represented a certain multiple of 1-1/4 inches (1-1/8-inch green dimension and 1/8-inch saw kerf) of radius from the pith at a certain height in the tree.

The volume measurements for specific gravity were made by immersion, but the wood had been steamed after air-drying to 12 percent moisture content, in order to kill an insect infestation in the samples. This treatment caused the samples to recover some of the shrinkage that had occurred in drying, and raised their moisture content to an average of 14.6 percent. The specific gravity data are therefore a little lower than those determined for wood at 12 percent moisture content that has had normal shrinkage in drying, but they are valid for comparison.

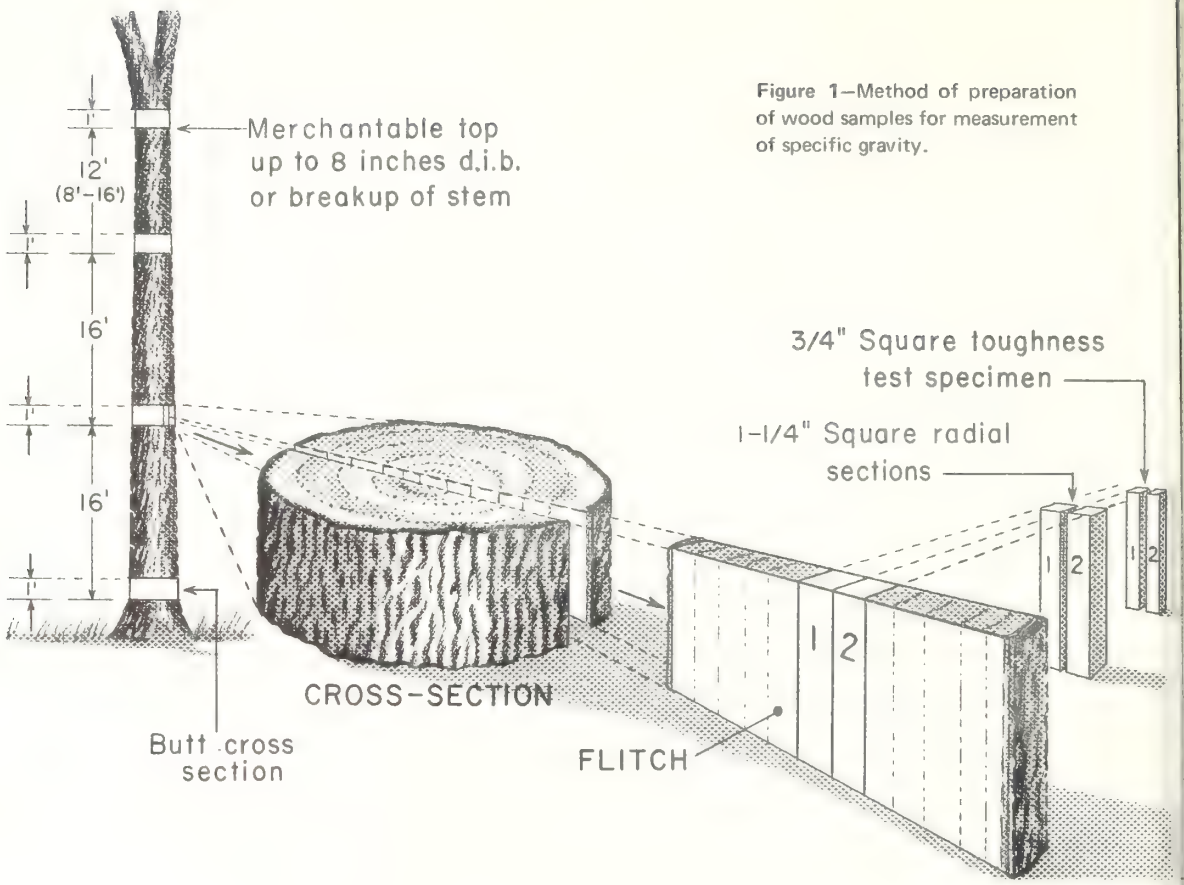


Figure 1—Method of preparation of wood samples for measurement of specific gravity.

# RESULTS AND DISCUSSION

## Specific Gravity of the Sample

The sample consisted of 1,759 toughness test sticks representing various radial segments at several heights in 50 trees. The grand mean specific gravity of these sticks was 0.603, with a coefficient of variation of 18.6 percent and a range among the sticks from 0.331 to 0.869. Specific gravity is obviously quite variable in the species; the usual coefficient of variation, based on tests of 50 United States mainland species, is 10 percent (U.S. Forest Serv., Forest Products Laboratory 1955).

## Specific Gravity of Individual Trees

Mean specific gravity per tree ranged from 0.431 to 0.694 with a coefficient of variation between means of 10.4 percent. Only five trees of the 50 had a mean specific gravity of less than 0.5, and four of these were in one stand.

## Specific Gravity of Stands

Among the 10 stands were several that ha generally similar site characteristics, but specif gravity varied considerably between them *(table 1* The stand highest in elevation (No. 8), had abnorma ly short trees and a significantly lower mean specif gravity than the other stands. Stand 9, which ha been planted on infertile, abandoned sugar cane lan was higher in mean specific gravity than the othe stands, but only significantly higher than five o them. These two stands also had lower coefficients o variation than any of the others. The coefficient o variation between stand means was 8.7 percent.

Spacing of trees around the sample trees was als measured and analyzed, but had no obvious relatio ship to specific gravity. Stands 5 and 9 had a mea spacing of 8 by 8 feet. Stand 12 was spaced 14 by 1 feet. The other stands were spaced 10 by 10 to 12 b 12 feet.

Table 1–*Specific gravity of robusta, by stand and site characteristics*

| Stand number | Age | Elevation | Rainfall | Mean dbh | Mean merchantable height | Mean specific gravity[1] | Coefficient of variation |
|---|---|---|---|---|---|---|---|
| | *Years* | *Feet* | *Inches* | | *Feet* | | *Percent* |
| 1 | 44 | 1,300 | 250 | 18.1 | 60 | 0.654 ab | 14.8 |
| 2 | 33 | 2,200 | 115 | 19.6 | 56 | .620 abc | 16.3 |
| 3 | 33 | 2,200 | 75 | 16.6 | 40 | .591 bc | 17.6 |
| 4 | 32 | 2,600 | 85 | 16.4 | 40 | .576 c | 18.6 |
| 5 | 34 | 2,000 | 100 | 16.9 | 48 | .562 c | 21.4 |
| 6 | 31 | 1,800 | 75 | 17.0 | 60 | .616 abc | 18.3 |
| 7 | 33 | 2,200 | 85 | 20.0 | 60 | .578 bc | 18.4 |
| 8 | 30 | 3,600 | 75 | 16.6 | 24 | .480 d | 13.7 |
| 9 | 35 | 1,600 | 225 | 16.2 | 44 | .661 a | 12.4 |
| 10 | 34 | 1,500 | 250 | 18.5 | 48 | .624 abc | 18.2 |
| Over-all means | | | | 17.6 | 48 | .603 | 18.6 |

[1]Values followed by the same letters do not differ significantly at the 5 percent level of probability.

## Specific Gravity of Size Classes

The sample included trees ranging in d.b.h. from 12.3 to 25.9 inches and in merchantable height from 16 to 88 feet. To see if specific gravity varied with tree size, I grouped the trees into four size classes based on their diameter inside bark at the top of the first log. This measure allowed fairly uniform classes with a more nearly equal representation of stands and trees in each class than did the measurements of d.b.h. or the diameter inside bark at the butt.

The mean specific gravity of the class of larger trees was highly significantly different from the other three means *(table 2)*. The other three means were not different from each other at the 5 percent level.

Except for two from stand 1, the trees in class 4 grew most rapidly in diameter, as indicated by the mean annual increment. Although this suggests that rapid growth produces wood of higher mean density than slow growth, probably the higher density value resulted from the greater proportion of dense, outer wood in the larger trees. The relationship does not hold for wood of stand 9, which though slowly grown in comparison to the other stands, had the highest mean specific gravity *(table 1)*. Regression analysis using the ratio of diameter inside bark at the top of the first log to age of the tree as the dependent variable and mean specific gravity at the 16-foot height for each tree as the independent variable showed only a poor relationship between the two. It yielded a correlation coefficient of only -0.143.

Table 2–*Specific gravity based on diameter inside bark at top of first log, by size class*

| Size class | Diameter range | Diameter growth per year[1] | Specific gravity[2] |
|---|---|---|---|
| | *Inches* | | |
| 1 | 7.6- 9.9 | 0.263 | 0.581 a |
| 2 | 10.0-11.9 | .322 | .595 a |
| 3 | 12.0-13.9 | .390 | .595 a |
| 4 | 14.0-18.4 | .444 | .625 b |

[1]Diameter at 16 feet divided by stand age.
[2]Values followed by the same letter do not differ significantly at the 1 percent level of probability.

## Specific Gravity Variation Within Trees

Within trees, specific gravity was also quite variable. The coefficient of variation ranged from 7.8 percent for the least variable tree to 23.0 percent for the most. For only two trees was it below 10 percent.

Within a single tree, the largest range in specific gravity was 0.357 to 0.817, a difference of 0.460. The low value was from a sample at the butt of the first log next to the pith. The high value sample was 64 feet up the tree and 3 inches out from the pith. In the butt cross section of this same tree, the wood next to the pith was 0.357, and 6 inches from the pith it was 0.755, a difference of almost 0.4. This was the largest variation in a single cross section.

Most other trees were almost as variable, and differences of 0.3 and more between the highest and lowest value sample in a tree were quite common. Variation was usually greatest in individual cross sections from low in the trees–at the butt and at 16 feet. In many of these cross sections there were specific gravity differences of more than 0.3 between inner and outer wood.

In the consolidated data for all stands, a consistent trend of increase in specific gravity with distance from the pith and height is indicated *(table 3)*, although somewhat masked. When the data are grouped into the four size classes and when values based on only a very few samples are dropped, the trend is very clear *(fig. 2)*.

Robusta does not produce growth rings in Hawaii, and so periodic growth cannot be determined from its wood. General observations, coupled with a few available periodic height and diameter measurements of robusta trees in plantations, indicate that growth is rapid for the first 10 years or so. Growth rate then gradually slows as the trees increase in age.

Table 3–*Specific gravity and sampling frequency, by radius and height in tree*

| Height in tree (feet) | Number of samples | Mean specific gravity | Specific gravity and number of samples for each 1¼ inch radial increment[1] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1¼ | 2½ | 3¾ | 5 | 6¼ | 7½ | 8¾ | 10 | 11¼ |
| 88 | 7 | 0.723 | 0.676(2) | 0.706(2) | 0.767(2) | 0.763(1) | | | | | |
| 80 | 18 | .715 | .666(6) | .722(6) | .754(5) | .771(1) | | | | | |
| 76 | 6 | .698 | .641(2) | .684(2) | .768(2) | | | | | | |
| 64 | 101 | .696 | .635(28) | .693(28) | .739(26) | .735(15) | .724(4) | | | | |
| 60 | 12 | .649 | .531(4) | .666(4) | .749(4) | | | | | | |
| 56 | 22 | .670 | .600(6) | .657(6) | .727(6) | .710(3) | .704(1) | | | | |
| 48 | 223 | .665 | .573(60) | .644(60) | .719(56) | .742(34) | .750(13) | .662(1) | | | |
| 44 | 13 | .610 | .456(2) | .555(2) | .628(2) | .652(2) | .656(2) | .671(2) | .694(1) | | |
| 40 | 15 | .664 | .527(4) | .655(4) | .694(4) | .808(2) | | | | | |
| 32 | 354 | .636 | .538(88) | .604(88) | .678(85) | .712(55) | .732(28) | .723(10) | | | |
| 24 | 18 | .580 | .528(6) | .589(6) | .646(5) | .514(1) | | | | | |
| 16 | 438 | .594 | .492(98) | .548(98) | .625(98) | .664(76) | .686(44) | .677(17) | .662(6) | .701(1) | |
| Butt | 531 | .532 | .436(100) | .461(100) | .527(99) | .579(93) | .620(70) | .632(38) | .616(16) | .664(10) | .644(4) |
| Total Mean | 1,759 | .603 | .517(406) | .571(406) | .640(394) | .658(282) | .672(163) | .658(68) | .631(23) | .667(11) | .644(4) |

[1]Distance of outer edge of sample from pith.

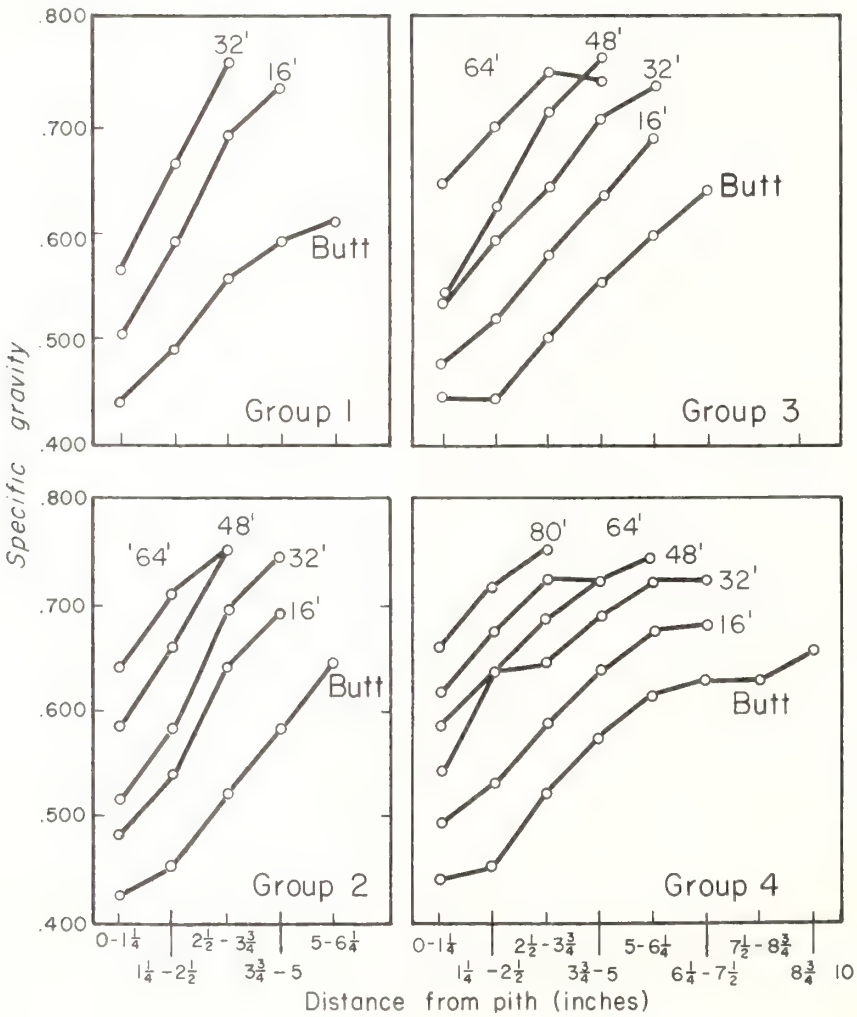


**Figure 2**–Specific gravity along radii of major cross sections, by height in tree and distance from pith, in four size classes determined by diameter inside bark at top of first log: Group 1, 7.6-9.9 inches; Group 2, 10.0-11.9 inches; Group 3, 12.0-13.9 inches; Group 4, 14.0-18.4 inches.

It is apparent that specific gravity of the wood oduced is related to diameter growth rate. Diameter owth rate is in turn probably related to cambium e. When the tree is very young and very fast owing, low density juvenile wood is produced. ensity increases as diameter growth rate decreases d mature wood is produced. The relation between mbium age and specific gravity increase is not so ear cut with regards to growth in height, because nsity increase with height is much greater than crease with diameter in wood produced by cam- um of the same age. A 6-inch diameter robusta tree usually over 40 feet tall. The specific gravity of ood 3 inches out from the pith at the butt of such a ee is usually less than that of wood at the pith at 32 et up in the tree, even though the wood at this ight in the tree was produced by the cambium at out the same time as the wood at the butt *(fig. 2).* is indicates that some of the increase in wood nsity with height is independent of the age, and ssibly the reproductive rate, of the cambium.

## Specific Gravity Variation Between Young Stands

To determine if there was any consistent propensi- of certain stands to produce high or low density od, I compared the mean specific gravity of each the first three radial increments at the butt and -foot cross sections *(table 4).* Any increment from e stand should be similar in age and stage of growth one from another stand, and the 1-1/4-inch rement at the butt section should be nearly ntical in all stands.

Stand 9 produced wood that was significantly hser, even close to the pith, than the wood of all t one of the other stands *(table 4).* The greater an specific gravity of trees in stands 1 and 9, when vested *(table 1),* was already present in the butts these trees when they were only about 6 inches in meter at the butt. It would probably have been sible to predict that these stands would have ser wood on the basis of increment cores taken ly in their life. There was not, however, a good ly indication that stand 8 would have less dense od than any other stand. The trend towards low sity in stands 4, 5, 7, and 8 is present in most ements, but is not sufficiently consistent to vide a basis for prediction.

There is no obvious explanation for the initially ser wood in stands 1 and 9. As has been tioned, stand 9 was growing on infertile soil of an ndoned sugar cane plantation. This soil may have been limiting in some nutrient essential to lower density wood production; stand 9 was obviously below normal size for its age. Stand 1, on the other hand, had grown at an impressive rate. It was on a shallow soil formed on a pahoehoe lava flow of Mauna Loa volcano and thus was different from all the other stands, which were on deep soils formed on Mauna Kea cinder deposits. Possibly stand 1 soil also had a nutrient makeup different from the others.

Table 4—*Stand mean specific gravity in descending order, for first three increments of radius at butt and 16-foot cross sections*

| Stand number | 1¼ inches from pith specific gravity[1] | Stand number | 2½ inches from pith specific gravity[1] | Stand number | 3¾ inches from pith specific gravity[1] |
|---|---|---|---|---|---|
| | BUTT CROSS SECTION | | | | |
| 9 | 0.515 a | 9 | 0.587 a | 9 | 0.653 a |
| 10 | .453 ab | 1 | .510 b | 1 | .578 a |
| 2 | .452 ab | 2 | .467 c | 10 | .553 b |
| 6 | .441 ab | 10 | .459 cd | 6 | .524 bc |
| 8 | .438 bc | 6 | .452 cd | 3 | .524 bc |
| 1 | .436 bc | 3 | .443 cd | 2 | .523 bc |
| 3 | .423 bcd | 4 | .435 cd | 4 | .517 bc |
| 7 | .419 bcd | 5 | .419 d | 5 | .486 bc |
| 5 | .393 cd | 8 | .418 d | 8 | .459 c |
| 4 | .388 d | 7 | .418 d | 7 | .456 c |
| | 16-FOOT CROSS SECTION | | | | |
| 1 | .550 a | 9 | .661 a | 9 | .720 a |
| 9 | .548 a | 1 | .624 a | 1 | .694 ab |
| 2 | .506 b | 2 | .567 b | 6 | .650 bc |
| 3 | .496 b | 3 | .563 bc | 10 | .639 bc |
| 6 | .490 bc | 6 | .548 bc | 3 | .639 bc |
| 10 | .487 bc | 10 | .533 bcd | 4 | .616 c |
| 7 | .483 bc | 4 | .524 bcd | 2 | .607 cd |
| 4 | .468 bc | 5 | .508 cd | 5 | .597 cd |
| 5 | .449 c | 8 | .484 d | 8 | .543 d |
| 8 | .446 c | 7 | .477 d | 7 | .540 d |

[1]Values followed by the same letters within each group do not differ significantly at the 5 percent level of probability.

## Specific Gravity of Brittleheart and Sound Wood

Brittleheart is a core of brash wood near the pith. It is usually made up of rapidly grown, low-density juvenile wood. This wood is crushed by the long-term loading of longitudinal growth stress and is brash because it is full of minute compression failures. Such wood is essentially useless for lumber products and is usually discarded.

All the samples of this study were processed through a U.S. Forest Products Laboratory toughness testing machine. Those samples that had a brash type of failure were considered to be brittleheart.

Although brittleheart is formed of low density wood that is readily crushed, all low density wood is not brittleheart. Wood taken from near the pith of very young trees, though of low specific gravity, is not abnormally brash (Dadswell and Langlands 1934). It only becomes brash as the trees get older and larger, developing compression failures due to growth stresses. Specific gravity remains constant.

Nevertheless, one of the best means of segregating brittleheart from sound, normal wood is by weight, because in sawlog-size trees, there is a very strong relation between low density and brittleheart *(table 5)*. There were 577 samples of brittleheart with a mean specific gravity of 0.503. This mean was found by the t test to be significantly (1 percent level) different from the mean of the 1,182 samples of sound heartwood and sapwood, which was 0.651. In each stand, brittleheart was significantly less dense than sound wood. But, illustrating that all low density wood is not brittleheart, the sound wood o stand 8 is quite close in specific gravity to th brittleheart of stands 2, 3, 4, 5, 6, 7, and 10.

Table 5–*Mean specific gravity of brittleheart and sound wood, by stand*

| Stand number | Specific Gravity | | |
|---|---|---|---|
| | All wood[1] | Brittleheart[1] | Sound wood[1] |
| 9 | 0.661 a | 0.572 a | 0.693 a |
| 1 | .654 ab | .547 a | .691 a |
| 10 | .624 abc | .496 b | .674 ab |
| 2 | .620 abc | .499 bc | .657 b |
| 6 | .616 abc | .514 b | .655 bc |
| 3 | .591 bc | .494 bc | .627 d |
| 7 | .578 bc | .499 bc | .634 cd |
| 4 | .576 c | .487 c | .629 d |
| 5 | .562 c | .475 c | .653 bc |
| 8 | .480 d | .442 d | .496 e |
| Average | .603 | .503 | .651 |

[1]Figures followed by the same letters within each column are not significantly different at the 5 percent level of probability.

Table 6–*Specific gravity of brittleheart, sound heartwood and part or all sapwood, by size[1] class*

| Item | Class | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Diameter range (inches) | 7.6-9.9 | 10.0-11.9 | 12.0-13.9 | 14.0-18.4 |
| Brittleheart specific gravity[2] | .499 ab | .490 a | .500 ab | .522 b |
| Sound heart specific gravity[2] | .584 c | .614 d | .608 cd | .640 e |
| Sapwood and part sapwood specific gravity[2] | .691 f | .703 f | .707 f | .716 f |

[1]Based on diameter inside bark at top of first log.
[2]Values followed by the same letters within each row an column do not differ significantly at the 1 percent level o probabiltiy.

If the specific gravity values of brittleheart, soun heartwood, and sapwood or part sapwood are sepa ated by size class *(table 6)*, it is seen that the relatio between brittleheart and sound wood specific gravit holds for trees of all sizes. Further, sapwood and par sapwood is significantly denser than sound hear wood. This is not surprising, since specific gravity ha been shown to increase consistently with diamete and the three types of wood occupy distinct position with respect to diameter.

It should be possible to control a considerable par of the variation in robusta wood density by sortin the wood into brittleheart, sound heartwood, an sapwood or part sapwood.

# SUMMARY AND CONCLUSIONS

Skolmen, Roger G.
1972. **Specific gravity variation in robusta eucalyptus grown in Hawaii.** Berkeley, Calif., Pacific SW. Forest & Range Exp. Stn., 7 p., illus. (USDA Forest Serv. Res. Paper PSW-78)
*Oxford:* 176.1 *Eucalyptus robusta:* 812.31[–015.26 + 812.712].
*Retrieval Terms: Eucalyptus robusta;* wood density; specific gravity; brittleheart; variation; Hawaii.

Tests on samples from 50 trees indicated that the specific gravity of robusta eucalyptus wood varies markedly within trees, between trees, and between stands. Mean specific gravity was 0.603; range wa 0.331 to 0.869 for the entire sample. Most of th variation within trees results from a consistent in

crease in wood density with diameter and height increase. The range within one cross section was 0.357 to 0.755, and the largest range for a single tree was 0.357 to 0.817. Some of the variation between stands may be caused by site factors, because abnormally high or low specific gravity is related to the location where grown, or the stand, and shows up early in the life of the stand. Variation in specific gravity between stands is not obviously related to differences in growth rate between stands, although the slowest growing stand had the highest density wood.

Because robusta wood density is variable, the species is difficult to handle in many manufacturing operations. In seasoning, the denser wood loses and gains moisture much more slowly than the less dense wood. Wood cutting tools adjusted for average density may gouge low density wood and skip over or jam on high density wood. Gluing and finishing problems may also result from density variation.

To reduce the manufacturing problems, wood should be carefully sorted by weight during grading. This is already done to some extent when brittleheart and suspected brittleheart are removed on the mill floor and at the green chain. But considerable variation in wood density still exists in sound heartwood and sapwood. Because specific gravity increases with diameter, sorting sound wood into "all heartwood" and "part or all sapwood" would further decrease variation. Because specific gravity increases with height, sorting of logs into "butts" and "uppers" before sawing would also be a means of reducing variation. This would also have the effect of separating the stronger, high density wood of the upper logs from the weaker but more easily worked wood of the butt logs. Lastly, logs should be plain- or flat-sawed if possible, because boards so sawn contain less density variation than quarter-sawed boards.

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1972. **Specific gravity variation in robusta eucalyptus grown in Hawaii.** Berkeley, Calif., Pacific SW. Forest & Range Exp. Stn., 7 p., illus. (USDA Forest Serv. Res. Paper PSW-78)

The specific gravity (air-dry volume, ovendry weight) of *Eucalyptus robusta* wood was tested within and between trees from 10 stands. Mean specific gravity was 0.603, but the range in individual samples for 50 trees was 0.331 to 0.869, and was 0.357 to 0.755 within one cross section. A consistent increase was recorded in all trees from pith to cambium and from butt to top. Mean for brittleheart (brash wood near the pith) was 0.503, considerably lower than that for normal wood at 0.651. Manufacturing problems caused by density variation could be reduced by sorting before sawing and during grading.

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PACIFIC SOUTHWEST
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Experiment Station

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BOX 245, BERKELEY, CALIFORNIA 94701

# FIRE PREVENTION IN CALIFORNIA'S RIVERSIDE COUNTY HEADSTART PROJECT... an evaluation

William S. Folkman  Jean Taylor

USDA FOREST SERVICE RESEARCH PAPER PSW-79 1972

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## The Authors

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**JEAN TAYLOR** was formerly an education specialist with the Station's fire prevention research unit. She earned a bachelor's degree in education at the New York State University (1951).

## ACKNOWLEDGMENTS

This study was undertaken as part of an ongoing program of research into the problem of man-caused forest fires supported jointly by the Pacific Southwest Forest and Range Experiment Station and the California Division of Forestry. We acknowledge the assistance of the following persons: John G. Jegi, director, Educational Planning Center, Contra Costa County Department of Education, and his staff, who helped in planning the evaluation; Mary Giorgi, principal of the John Baldwin School, San Ramon, Calif.; Frances Forester, director, Fresno City Preschool Department, and Dr. Louise Pierce, early childhood development specialist of that Department, who provided a valuable critical preuse examination of the content of the prevention materials as related to the program objectives; Dr. Carolyn Stern, Department of Education, University of California, Los Angeles, and her staff, who developed the testing instruments; Dollie Lynch, director, Riverside County Headstart project, her successor Jane Horsfield, Elizabeth Neumann, staff psychologist, and various teachers and staff of the Riverside County Headstart Project who gave advice and assistance in carrying out the evaluation.

Richard J. Ernest, Rex Griggs, and John Ferguson, all of the California Division of Forestry, had the primary responsibility for developing the fire prevention materials, assisted by an advisory committee of Headstart personnel composed of Mrs. Lynch, Lucille Taylor, Mrs. Neumann, Miss Horsfield, Geraldine Yates, Anita Matthews, and Wilma Miller.

When the California Division of Forestry first attempted to incorporate fire prevention education in the Headstart Project in Riverside County, available materials were found to be generally unsuitable for use with preschool children. Division personnel, together with a committee of Headstart teachers, using such available items as were considered appropriate and devising new ones, developed a set of materials which they felt would be effective at the age level of the Headstart children. These materials were introduced into half of the Headstart classes (44 classes) in Riverside County during the 1968-69 school year. The Fire Prevention Research unit of the Pacific Southwest Forest and Range Experiment Station agreed to evaluate the program. This paper reports the results of this evaluation.[1]

Evaluation is an ongoing process that ideally should proceed from the original conception of the idea through its implementation to the adoption or rejection of the project. In this instance, evaluation was not requested until the pilot program was to be implemented, but we were able to establish a semi-controlled trial situation.

## PLACE OF FIRE PREVENTION IN HEADSTART

Grass, brush, and timber fires started by children are an increasing concern to fire prevention agencies in many parts of the country. In 1954, children accounted for 10.5 percent of the 1,955 man-caused forest fires on land under the California Division of Forestry responsibility. Since that time, both the number and percentage of child-caused fires has increased steadily. In 1968, children were responsible for 23.5 percent of the 4,034 man-caused fires. Other populous parts of the country recognize a similar problem. Among the 20 Northeastern and Lake States, child-caused fires are not reported separately, but they are the major component of the general cause category—"Miscellaneous."[2] In the last 4 years reported (1964-1967), this category ranked first in 2 years and second in the other 2 years. In two of the States, New York and Vermont, which do show child-caused fires separately, these ranked fourth and third, respectively, in 1967.

The Division of Forestry's interest in reaching Headstart children with an effective fire prevention program is based on findings that children responsible for fire starts are often quite young. A recent analysis of fire reports in the Los Angeles Forest area showed 12 percent of the children involved to be under 5 years old (Folkman 1966, p. 2) and nearly 75 percent 10 years old or younger. Analyses from other areas show a similar age distribution. Most efforts at fire prevention education in the schools, however, are generally directed at older children—usually about the fifth grade or 11 to 12 years. Through Headstart, the Division hopes to reach children early in their fire-experimenting stage.

The Headstart Project includes a large number of preschool children otherwise inaccessible to this type of educational approach. Although other preschool and kindergarten children may be reached later, there are indications that work with Headstart children is particularly appropriate. Research provides evidence of higher rates of accidents among children from poor families (Deutsch 1961, p. 95). If we consider this type of fire starting as basically a form of accident, we might expect Headstart children to be disproportionately subject to it. Observations of fire investigation officers in Riverside County suggest that the supposition may well be justified there.

Anticipated trends in population change, residential development patterns, and recreational activities are expected to intensify the problem of child-caused fires as more and more children are brought into closer contact with high fire-risk wildlands. The obvious danger to children and to others,

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[1] Since this report was issued, the California Division of Forestry has used the findings in the study to develop an improved version of its fire prevention educational kit. This kit is available for purchase, at cost, from the State Forester, California Division of Forestry, 1416 Ninth Street, Sacramento, California 95814. Price is $6.30 per kit.

[2] Personal correspondence from the office of Cooperative Forest Fire Control, Northeastern Area, State and Private Forestry, U.S. Forest Service, Upper Darby, Pa.

and the likelihood of both economic losses and other losses not easily measured, justify attempts to teach fire prevention to young children.

The families of Headstart children do little recreational camping. These children contribute to the forest-fire risk mainly as their home environment exposes them to high hazard grass and brushland. Children are more frequently exposed, however, t the hazard of structural fires, and the possibility o injury or death to themselves and to others is muc higher. The Headstart prevention program, therefore places considerable emphasis on home fire safety an fire in general. It is not exclusively a forest-fir prevention educational effort.

# CAUSES OF FIRE-STARTING BEHAVIOR IN CHILDREN

## *Relation to Goals of the Program*

The aim of the fire prevention program in Headstart was to change the fire related attitudes, knowledge, and behavior of the children, so that child-caused fires would be reduced. Fire incidence is influenced by so many uncontrollable and unaccountable factors, such as weather and topography, that it could not be used as a direct measure of the change produced. Consequently, the program's success has been measured in terms of observable changes in the children's cognition, attitudes, and behavior in areas considered to be related to their fire activities.

## *Relation to Other Findings*

The causes of fire-starting behavior are not well understood, but in developing the program, the Division assumed the influence of curiosity, lack of understanding of cause and effect relationships, imitation, aggression, and risk taking. (No attempt was made to deal with the last two causes directly because they were not considered amenable to the approach used in the program.) The characteristics of fire have made it a potent, fascinating, and awesome theme in folklore, ritual, and myth of virtually every primitive culture through the ages (Frazer 1930, Bachelard 1964). The literature suggests an almost universal interest among children, especially boys. This sex bias supports the psychoanalytical linkage of fire fascination to male psychosexual development. It is also quite clear that fire, like sexplay, is an object of the most general prohibition for children. There are no data on the relative frequency of fire play in different cultures.

The literature on firesetting is fragmentary, and most of it is of dubious validity. It consists mainly of isolated anecdotal reports based on very few cases, buttressed by psychoanalytical theorizing about persons who repeatedly started fires (Kaufman *et al.* 1961, Nurcombe 1964, Rothstein 1963, Seigel 1957, Sturup 1955, Yarnell 1940). Fire investigation reports show that a small minority of children are involved in such multiple fire sets. Although they collectively account for only a small proportion of the total fires, they have nevertheless received most research attention. Siegelman and Folkman (1971) found the following characteristics associated with incendiarism in children: hyperactivity, aggression, psychomatic difficulties, learning problems, behavior problems, and family trauma. The frustration engendered by these handicaps usually precipitated an acting out of hostility that frequently involved fire. A tentative typology identifies two different types of children: (1) the withdrawn, anxious child, with anger directed against himself, and (2) the restless child, subject to antisocial behavior, with anger directed outside himself. Although for both, the anger stems from essentially the same pressures, firesetting means different things to these different types of children. To the first, it may represent a cry for help—a plea for adult authority to help him deal with feelings too big, too dangerous, for him to master himself. To the other it is a means of revenge—a further way to increase his potency to gain attention, and perhaps the awed admiration of adults. Probably both kinds of feelings are present to some degree in any deliberate setting of fires.

Most fires, however, are not the result of such pathological behavior. Many are accidental; others, although deliberately set, simply get out of control, a development neither anticipated nor desired.

Research on this most prevalent type of child-caused fires is virtually nonexistent. The findings from the studies of pathological cases have some bearing, but most insights as to its causation may be gleaned from the slightly more plentiful studies of other forms of childhood accidents. These works suggest that a child's natural curiosity, sometimes coupled with an attempt to imitate an adult or older child, may place him where his lack of knowledge of cause and effect prevents his control or prediction of

e consequences. The incident thus becomes part of e record of a fire control agency. The number of ch incidents is large. The number of similar actions, nilarly motivated, that do not result in a reportable e accident is unknown but must be many times ger than the number of reported fires.

At one time considerable research attention was ven to the concept of "accident proneness." More cent research has questioned the concept, especially it was sometimes defined as the result of an conscious desire to have an accident (start a fire). atistically different accident rates for different dividuals are observed, but a more parsimonious planation is that the differential represents failure learn skills in coping with potentially dangerous uations, rather than subconscious pressures to flict pain on self or others. Clinical cases have been ported by various psychiatrists of a neurotic tenncy on the part of some individuals to inflict f-injury through deliberate accidents, but it is estionable whether such "accident proneness" exins all or even most instances of high accident quence. We would expect to find in any given riod a certain proportion of the public suffering a gh number of accidents by chance alone, since ance does play a part in most accidents.

Neither learning theory nor other studies give us a mpletely satisfactory model for understanding fire cidents. Evidence of higher accident rates among ver-class children is believed to be related to a low el of control of the environment by adults. In ner groups, such control reduces the opportunities accidents to happen. In addition to the economic d cognitive barriers to change, there is often a alistic attitude of parents that accidents are inevile and that some danger always exists. The ver-class child has more independence at an early , thus more opportunity within a limited sphere individual exploration and activity. Consequently, may have a higher early accident rate, but if he vives, he may have a more average one as he omes physically capable and consequently better e to generalize.

## Relation to Fire Prevention Education

Incomplete as it is, our understanding of why dren start fires supports the attempt to educate m to use of fire safely. Given the child's fascion with fire, and the general use of fire in our iety, it would be highly unrealistic for any vention program to set as its goal the complete elimination of fire play. To slow its increase, and perhaps reduce its incidence, would seem feasible, however. Of equal importance would be the direction of fire fascination into safer channels.

Literature on the teaching of fire prevention is limited. Usually fire prevention is incidental to conservation and natural resource programs. Reports[3] evaluating such programs are generally descriptive or impressionistic, and include little or no data. The fire prevention component is not separately analyzed. The programs are generally aimed at the higher elementary grades or the high school levels.

A recent study reports an investigation into the specific teaching of conservation and forest fire prevention principles to boys and girls of kindergarten and early elementary grades (Gladen and Carkin 1970). The investigators found that significant learning did take place in the study population, in contrast to a control sample, in response to the instructional materials. The study did not attempt to determine whether or not principles learned produced desired changes in conservation-related behavior.

In the few years that the Headstart Project has been in existence, the U.S. Office of Economic Opportunity has sponsored a number of studies designed to evaluate the effects of the program on the participants' readiness for a regular school experience.[4] These studies have used existing or improved measuring devices in such areas as cognitive skills, perceptual-motor functioning skills, and school-specific readiness skills. Although none of these

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[3]Typical of these reports are: Albert H. H. Dorsey, *The conservation curriculum improvement project: a statewide effort to promote interest and action in environmental education.*, Sci. Teacher 34: 49-51, 1967; Robert W. George, *A comparative analysis of conservation attitude in situations where conservation education is a part of the educational experience,* (unpublished Ph.D. thesis on file at Michigan State Univ.) 1966; R. G. Hanchey, *The teaching of conservation and resource at the sixth-grade level,* School Activities 33: 234-235, 1962.

[4]The following are typical of these studies: Elmer Van Egmond, and others, *Operation Headstart–an evaluation.* Lesley College, Cambridge, Mass., 1966; Sherwood B. Chorost, Kenneth M. Goldstein, and Richard M. Silberstein, *An evaluation of the effects of a summer Headstart program,* Wakoff Research Center, Staten Island Mental Health Society, 657 Carleton Ave., Staten Island, N.Y. 10301, 1967; Douglas Holmes, and Monica Bychowski Holmes, *Evaulation of two associated YM-YWHA Headstart programs,* YM-YWHA of Greater New York, 33 west 60 St., New York, N.Y., 10023, 1965; Philip J. Porter, *Evaluation of a Headstart educational program in Cambridge, Massachusetts,* Harvard University, Cambridge, Mass., 1965.

instruments are directly appropriate to this study, they suggested methods of approach.

A prevention program must recognize that fire is fascinating to children and must satisfy their curiosity in acceptable ways. On the other hand, care must be taken that the program activity does satisfy this curiosity and not merely stimulate it. An opportunity seems necessary for each child to experiment directly with fire safely and under supervision.

Much of a child's play, including fire play, has the function, if not the conscious purpose, of providing practice in roles appropriate to later life. A prevention program, therefore, should include opportunities for the children to observe significant persons (parents, teachers, and others) using fire safely and legitimately; ideally such a program should provide opportunities for the children to participate.

The conceptual level required to perceive causal relationships is not reached suddenly. Instead, children develop precausal and causal explanations for events over a fairly long period. The age at which a stable notion of causality is achieved is probably determined by a combination of interrelated but not necessarily interdependent factors: intellectual level, verbal development, experience, and possibly some innate maturational factor. Children of the Headstart age are just approaching this conceptual level, and their stage of development is not easy to predict. Although generally impoverished in experience with school-oriented activities, Headstart children may be much more sophisticated than more protected upper-class children in other activities to which their home environment exposes them. Fire prevention programs should take this possibility into consideration.

Children with fire problems related to emotional and behavioral difficulties are not apt to be encountered at the preschool level. (A few were reported in interviews with teachers during the course of the study.) They generally begin to show up in the second or third grade when reading problems and other difficulties in coping with school are added to home-centered frustrations. Although it may not be possible at this early age to identify potential "poor risks," some may be prevented from developing. A fire prevention program may provide the therapy needed to treat "the fire within" such children as they are educated about "the fire without."

A fire prevention program for the preschool child must recognize that he is moving out of dependence for safety upon his parents (or other adults) to greater reliance on his own ability to perceive and react to hazardous situations. Such a program has three somewhat conflicting requirements:

1. The child must be protected against excessive injury from accidents; underprotection places him in situations beyond his ability to control or interpret.

2. The child must be taught skills in avoiding accidents; he must learn to *see* danger in the environment and learn how to react to it. (This would seem to require some exposure to potential fire-producing situations.)

3. Finally, the child must not be overtrained to the point of ensuring his safety at too high a cost in other values—such as enterprise and achievement.

In summary, the goals of the California Division of Forestry fire prevention program in Headstart (i.e., to produce desirable and observable changes in the children's fire-related cognition, attitudes and behavior) appear consistent with the causes of fire-starting behavior of normal children, as these are currently understood, namely, curiosity, lack of understanding of fire cause-and-effect relationships, and imitative behavior. To some extent the program may also have some bearing on aggressive and risk-taking behavior of potential fire problem children. This was not an aim of the developers of the program, however, and there was some doubt whether its success could be evaluated.

## HEADSTART FIRE PREVENTION KIT

Before use, the kit of fire prevention materials that had been assembled by Division and Headstart personnel was critically examined by the evaluation research staff and several early-childhood-education specialists. In general, the contents were found to be in harmony with the stated objectives of the program, but some changes in form or content was suggested. Time prevented any immediate action on these suggestions, however, other than the discarding of several specific items considered to have a negative teaching effect.

The Headstart fire prevention materials were developed (1) to satisfy normal curiosity about fire; (2) to improve understanding of the cause-and-effect relationships between the child's actions and the production of fire, and his actions and the resulting harmful effects to himself, to other people, and to his environment; and (3) to develop or reinforce positive

ttitudes toward fire-safe behavior, primarily by roviding positive models of such behavior. The chievement of these objectives is expected to reduce he incidence of illegal fires started by children.

The kit consists of seven sections:

Unit A. Teacher Information
Unit B. Introduction to Fire
Unit C. Fire Prevention
Unit D. Introduction to Smokey
Unit E. Christmas
Unit F. Conservation
Unit G. Smart Cookie–Dumb Cookie.

Unit A, the Teacher Information folder, contains a ief introduction to the objectives of the program d to the materials and supplemental aids provided. also contains a table of contents, coloring sheets, several posters, and a list of local fire prevention contacts. The other folders each contain a one- or two-page information sheet for the teacher, supplemental materials such as posters, coloring sheets, and adhesive badges, and in some instances leaflets to be sent home to the parents. An order form for any or all of four films is enclosed in each folder. These films are briefly described, but no suggestions are given on the form as to where they might most appropriately be used. The principal component of each folder, is a set of specially prepared 11- by 17-inch colored illustrations to be used in an aural-visual presentation. Suggested comment by the teachers is in Spanish and English on the reverse of each illustration. The content of the different units is described more fully in the section "Reactions to Specific Units and Items."

# EVALUATION OF CLASSROOM USE OF KIT

The effectiveness of the Headstart fire prevention rogram was assessed in terms of observable changes the children's cognition, attitudes, and behavior onsidered to be related to their fire activities. pecifically, the evaluation attempted to determine he extent to which the kit of materials achieved the hree objectives that guided its preparation, as set orth in the preceding section.

## *Methods*

### stablishing Experimental and Control Groups

The population to be studied was about 1,500 ildren enrolled in the Riverside County Headstart roject. There were 88 classes, with about 15 children r class, in 30 locations throughout the county.

With the assistance of Headstart personnel, classes ere matched as closely as data permitted on such haracteristics as location (rural-urban, desert-non-sert), ethnic composition, parental occupation, and pe of sponsoring organization. Classes in these 44 atched pairs were randomly assigned to either the perimental group or the control group. Two of the perimental classes did not participate in the test ogram at the end of the year, leaving 42 classes in is group. Although the selection of experimental d control classes was intended to isolate the perimental variable–the fire prevention educational perience–it was not possible to structure the classes exactly as desired (*table 1* in Appendix) since no reassignments of pupils could be made. Significant differences between the two groups were detected for three of the characteristics studied–ethnic origin, family income, and whether or not the family was currently on welfare.

Under ethnic origin, we found that "other Caucasians" were significantly under-represented in the control classes. Whereas the category "not reported" was over-represented.

Children from families whose income was reported in the lowest category ($1,500 or more below Economic Opportunity Board [EOB] poverty level) were over-represented in the control classes, whereas the next lowest ($500 to $1,499 below EOB poverty level) was similarly over-represented in the experimental classes.

The proportion of children from families currently on welfare was slightly higher in the experimental classes than in the control classes. Again, however, there was over-representation in the control classes of children for whom this information was not available.

The lack of complete comparability between the two groups must be recognized in weighing the findings of this evaluation. Much of the difference noted may, however, be more apparent than real, because actual data were lacking. The findings reported below do not indicate that any of the characteristics that were significantly different in the two groups were related to differences in test scores.

### Handling Materials and Testing

The fire prevention materials were originally scheduled for use in November, or early December, 1968, but they did not become available to the classes until early January, 1969. The materials were used in the experimental classrooms during the remainder of the school year. Students in the control classes followed the regular curriculum and received no fire prevention education other than that which their teachers may customarily have given on their own initiative.

Teachers using the special materials were requested to keep logs of their use and associated activities. They were also asked to make subjective appraisals of pupil reaction to specific items from the kit of materials. Teachers' observations were supplemented by the reports of a specially trained person (Mrs. Taylor, co-author of this paper) not directly connected with the prevention program who visited the classrooms periodically to observe operations and interview teachers.

Toward the close of the school year, the children from the experimental and the control groups were tested and the results compared to determine the effects of the program. No pretest was used. Campbell and Stanley (1963, p. 195) advise against this when experimenting with the introduction of entirely new subject matter—particularly in the primary grades. The pretest, followed by a post-test using identical or highly similar unusual content, may distort the results as much as the experimental variable. Campbell and Stanley (1963) point out that the process of "blocking"—as used in our matching of pairs of extant, intact comparison groups, provide an increase in power of the significance test similar to that provided by the pretest.

The testing instruments were prepared[5] in three parallel forms (see Appendix) so as to assess more comprehensively the effectiveness of the experimental program without unduly taxing the children tested. The forms A, B, and C, were given in rotation in each class so that approximately equal numbers of children were tested with each form. Two types of test items were used. One section required the child to select an illustration from a series of three to indicate his response to the situation presented by the tester. There were 20 items in this section, 15 reflecting acquisition of concepts taught in the course, and 5 designed to assess affective changes. The second section was an oral question test, requiring "yes" or "no" answers. There were 25 items in this section, 18 information items, five affective items, and two probing fire experience. All test materials were translated into Spanish for use with children who might have problems with the English version, as judged by the teacher.

Individual testing in each class took two days. The picture test was given in two sessions and the oral in one, each session lasting from 10 to 15 minutes. Children were rewarded for their cooperation with Smokey Bear bookmarks, pins, etc. at each session. The tests were administered by a corps of specially trained women hired for the purpose. Several had facility in spoken Spanish.

## Results

Test results did not clearly demonstrate the value of the new prevention materials, although scores on all tests of concept acquisition were consistently higher for the experimental classes than for the control classes (*table 2* in Appendix). No significant differences were detectable between the two groups in scores on the affective items, which were designed to reflect attitude changes related to fire and its use.

### Some Influences on Test Scores

A number of influences undoubtedly tended to minimize the measured differences between the experimental and control classes. Those related to the prevention problem and the experimental materials will be considered more fully in the discussion of teacher reactions. Others include the method of using the materials and certain weaknesses in the testing.

The delay until midyear in getting the kits into classroom use seriously reduced the time available for a fair trial of the materials. A number of teachers felt that the fall of the year offered more appropriate occasions than the spring for using the materials. Their contention seems valid that had the kits been available for the full year, the results might have been more impressive.

To make the trial as nearly operational as possible, no attempt was made to influence the extent or manner of teachers' use of the materials. Similarly, teachers in the control classes were free to continue any prevention programs they were accustomed to presenting. This lack of control might be expected to reduce observable differences.

[5]Testing materials were prepared under the direction of Dr. Carolyn Stern by the staff of the Headstart Evaluation and Research office, Department of Education, University of California, Los Angeles. Modifications in materials and testing procedures resulting from pretest experience were made by the Experiment Station staff.

From the data reported below on the relationship f age to test scores and from the observation of assroom activities, it is apparent that the materials enerally were more suited to the maturity level of ie older children than they were to the younger nes, and that this was also true of the testing struments. Effective educational testing at any level resents many problems. In testing preschool chil-ren, most of these problems are compounded. Many f the problems were resolved, but there still remains me question as to how much the results, or lack of sults, of the testing depend on the experimental riable and how much they depend on the testing evices themselves.

### elation of Scores to Characteristics of Children and Teachers

The relationship of individual test scores to various haracteristics of the children was investigated. Data ere available on ethnic origin, family income, age, x, language spoken in the home, ability to speak nglish, welfare status of the family, and total umber in the family. Only age proved to have a gnificant relationship to test scores. The children nged in age from about 3-1/2 to over 6 years, with ie great majority evenly divided between the 4- and year-olds. The more mature children did much etter on all of the tests, but particularly better on ie pictorial section (*table 3* in Appendix). The fference between experimental and control classes as quite marked for the older children. Although no ppreciable difference between experimental and ntrol children 4 years old and under was detected the pictorial sections of the concept acquisition sts, the younger experimental group children did a tle better than the controls on the oral section.

Available data on such characteristics of the achers as ethnic origin, age, and previous education-experience were also examined to determine their lationship to test scores. No relationship was tablished with any of these characteristics.

### esponses to Individual Items

Examination of responses to individual test items owed that although experimental classes did con-tently better, differences in the main were small, d only occasionally reached statistical significance *bles 4,5* in Appendix). In a few instances, scores om control classes were higher than those from perimental classes, but these differences did not proach statistical significance, and were all in items r which the average scores for all groups were low.

### Relation of Scores to Frequency of Use of Materials

Variability in the extent of individual teachers' use of the materials was found to be reflected in the children's test scores. On the basis of data from the teachers' logs, classes in the experimental set were divided into two groups: those in which the teachers had used four or more of the units at least one time and those in which the materials were used less than this. The classes of teachers who did not submit logs of their activities were included in the low use group on the assumption that their failure to submit logs was indicative of their lack of interest. This is a very crude and merely quantitative measure of use of the materials. Differences in average test scores, however, show that the distinction has some validity. The more interested teachers did produce greater change in their students than did those who made relatively little use of the materials. Mean scores on the pictorial section of the test were 48.3 for high use, 46.4 for low use, and 42.4 for controls. For the oral section, scores were 60.3, 52.9, and 50.6 respectively.

Most children in all classes were already aware of some of the attributes of fire—that it keeps us warm, but that it also hurts if we are burned. They generally recognized city firemen and associated them with putting out fires. Many of the children recognized Smokey Bear. Exposure to the fire prevention program, however, did increase children's awareness of these things.

Significant differences in average scores of children from experimental and control classes for specific items reveal that children exposed to the program became better able to differentiate between "good" fires and "bad" fires. They were better able to identify situations conducive to the starting of uncontrolled fires, and recognize safe and unsafe fire-related behavior. For example, an increased proportion of the children were aware that playing with matches is unwise, and they were also more familiar with the proper thing to do if they found matches. They had become more familiar with Smokey Bear and associated him more readily with trees and their protection from fire.

Although there was a definite improvement in the areas mentioned above, the majority of students tested, experimental and control, were unable to identify high fire hazard situations and they still did not know what to do if they saw a fire. They also had difficulty comprehending the time needed for trees to grow after a fire, and few recognized a forest ranger (although, as indicated above, most were already familiar with a city fireman).

In the individual items devised to measure emotional responses to fire, there was no more evident difference between experimental and control groups than in the aggregate scores of these items. It was expected that the educational experience might help allay any overfearful reactions to fire that might exist, as well as reduce any excessive fascination with it. Some teachers reported observing such changes in some of their pupils. It is possible that the test was not sensitive enough to detect them. On the other hand, the fears of intensified fascination with fire receive no support from either the test results or the observations by teachers and others.

## *Resource Persons' Evaluation*

Most of the material in this section came from evaluation forms completed by the teachers using the kits and from observations of classroom activity and from discussions between teachers and the program observer. Other sources of information included meetings, both joint and separately, with Division of Forestry and Headstart personnel (especially the director and psychologist) and with members of the program testing team.

Of the 42 teachers in the experimental group, 33 (78.5 percent) turned in evaluation sheets at the end of the testing period. Two of the remaining nine left before the end of the year and their evaluation, if completed, could not be located. Two teachers reported extensive use of the materials, but did not complete the evaluation forms. The other five indicated that they had made little or no use of the kit.

### General Reactions

The teachers, with few exceptions, agreed that preschool children should be taught fire prevention. They considered the kit, on the whole, a valuable teaching aid. It should be noted that there is a dearth of material of any kind for the preschool curriculum. These Headstart teachers, therefore, are inclined to welcome any additions.

Two of the teachers in the experimental group were strongly negative about the program. One felt that any teaching of fire prevention to preschool children was inappropriate, as "fires are started because of a lack of supervision on the part of the parents. Children of this age should not be expected to be responsible for their own safety, and education should be geared to parents rather than to their children." She felt that the children might be stimulated by the materials, and by the testing experience as well, to set fires. She did suggest that the conservation unit could appropriately be used, provided the emphasis was on tree cultivation, rather than on forest fire prevention.

The other teacher felt that an intellectual approach to fire prevention would be ineffective–"children set fires because of adjustment problems." She also was concerned that the material might provoke fire-setting behavior.

These two teachers were among the five who made little or no use of the kits.

These issues concerned a few other teachers at first, but their attitudes were tempered by positive feelings about the materials provided and they were interested in trying out some of the units to observe the children's reactions. No adverse reactions were reported to have been precipitated by the use of the materials. On the contrary, one teacher stated that a child in her class who had formerly represented a fire problem was positively aided by the prevention lessons. He was now able to verbalize his concerns and direct his activities in more acceptable directions. A kindergarten teacher who had access to the materials reported a similar experience.

The California Division of Forestry personnel and the Headstart Teacher Committee who served as advisors in the development of the kit had expected that teachers would feel free, in fact encouraged, to contribute to the program by making adaptations and developing followup activities. Observation and teacher reports revealed that the materials had stimulated considerable creative work by some teachers. Several found the materials valuable as a springboard to experience in music, language development, and science, and to open communication with the children's families. It is evident, however, that if the kit is to have maximum value, most teachers will require more specific lesson plans and instructions, as well as patterns for followup activity.

Relatively few teachers ordered the supplementary materials available to them–films, tree seedlings, letters from Smokey, and so forth. Many of those who did order the supplementary materials that were suggested in the kits failed to receive them, or did not get them in time for them to be used.

The responses to specific questions on the evaluation sheets reveal some of the ways the teachers used the materials. Responses are summarized in *tables 6 and 7* in the Appendix.

The teachers' approach to time planning did not vary greatly. Approximately one hour was spent on each unit by the teachers reporting, for a total of five hours for the entire program. Periods of 15 or 20

ninutes were most popular for sessions, with little variation among units.

There was apparently a strong tendency to use the entire content of a unit in one lesson. Several teachers requested that the units be broken down into shorter lessons. Although some teachers did this themselves, most did not and attempted to reinforce the material by repetition.

Most of the teachers reported that their lessons were prepared directly from the materials provided, but with supplementation from their own resources. It was the classroom observer's impression, however, that a somewhat larger percentage than indicated worked directly from the prepared materials without supplementation. Very few teachers used the material only as a resource or for display.

The coloring sheets were most frequently mentioned in relation to supplementary activities. Coloring was frequently done in the class, but the sheets were usually sent home with the children. Teachers frequently reported parents' desire for such tangible evidence of their children's school activities.

The posters supplied were also much used, generally as classroom displays. All the posters observed had been painted or crayoned before being displayed. Other supplementary activities were infrequently carried out. About one-fourth of the teachers, however, reported the use of controlled fire experiments in conjunction with their use of the Introduction to Fire Unit.

Most of the classes were taught in English, but Spanish, or a mixture of Spanish and English was used in approximately one-fifth of the presentations.

In their general comments on the materials, many teachers noted that Smokey Bear was popular with the children. Virtually all children already knew about Smokey. These teachers felt that there would be greater interest in all of the units in the kit if Smokey were incorporated as a unifying theme. Several teachers reported using the Smokey Bear unit first in order to provide stronger motivation for the remaining units.

Several teachers felt that the story cards in all units except Unit G, Smart Cookie, Dumb Cookie, contained too many elements. The comment was made frequently that the language was too complicated for the younger children. The term "fire prevention," for example, was considered too difficult by a few teachers. Objections were made to inclusion of printed words on the posters, since the children could not read them.

Although the development committee had been concerned to make the artwork in the unit picture stories, and handout materials suitable to the preschool level, these still received criticism from some teachers as too sophisticated. Other teachers objected to the artwork for esthetic reasons.

For all units, all or nearly all the teachers responding answered yes to the question whether the unit was a desirable addition to the regular curriculum (*table 8* in the Appendix). There was similar agreement that children's behavior would be changed by their exposure to the units. The teachers also expressed a desire to use the materials again the following year. It should be noted, however, that no response was obtained to these three questions from two-fifths to nearly one-half of all the teachers in the program. We have no way of assessing the attitudes of those not responding, although it may be assumed that the more enthusiastic teachers would respond.

## Reactions to Specific Units and Items

Reactions of teachers and various resource persons to specific items are reported as they were communicated to the evaluation personnel.

Tabulations of information from the teachers' evaluation sheets provides some indication of the interest level engendered in the teachers (and by indirection, in the children) by each of the five units used. (Because materials were distributed after the holiday season, Unit E, Christmas, was not used as such, although individual items from the folder may have been incorporated in other units.) The number of teachers using a particular unit at least once was similar for all five units (*table 6* in Appendix), although three of the 33 teachers who reported using the Introduction to Fire Unit did not use the kit again after that. From the total number of lessons given, and the average number per teacher, it would appear that Introduction to Smokey evoked the most interest and Conservation the least.

### Unit A. Teacher Information

The brief introduction to the fire prevention program included in this unit emphasizes that it is not designed to restrict or limit the teachers' own plans or activities in any way. As has been noted, however, this freedom was not particularly appreciated. Many teachers would have felt more comfortable, apparently, with a more structured approach.

The four posters (FPE 32-35) included in this unit were displayed by the majority of teachers. It was generally agreed that the posters stimulated desired reactions in the children, especially FPE 32 and 34, both of which show the consequences of improper fire use. A few teachers did object to some details of

the artwork in FPE 34 (such as complicated style, use of wooden matches instead of more familiar book matches).

Of nine different coloring sheets in this unit, only three represent approved behavior. It was questioned whether any of the sheets should represent inappropriate behavior, particularly since the children could not read the words "YES" and "NO" which were prominent on the sheets. One teacher felt she partly solved the problem by coloring the "YES" green and "NO" red and associating this with the traffic signals familiar to the children.

### Unit B. Introduction to Fire

The stated objectives of this unit were (1) to introduce children to various types of fire, (2) to show how fire under control aids man, and (3) to point out some dangers if fire is misused.

A sequence of 13 pictures stress positive uses of fire and consequences of misuse. Cause and effect relationships are treated impersonally, in the main, although the role of father and mother is brought in in several instances. Poster 44b-12 portrays the consequence of a child's playing with a match, but otherwise the role of the child in fire use is not brought out. The impersonal wording on poster 44b-2 implies that children may legitimately use matches.

The teacher's information sheet mentions that many children, through curiosity, may experiment with fire and suggests that teachers may wish to conduct experiments with fire for the children. Specific examples, procedures, and precautions are not given, however. Handouts for parents include trash burning tips, safety precautions with gas heaters, and a warning to keep matches away from children. (Teachers and parents could provide models for proper fire behavior and positive attitudes toward fire if they translated this kind of brief generalized advice into specific action.)

Many teachers said that the kit should emphasize more positive uses of fire, and asked for more specific suggestions for conducting fire experiments. Activities used or suggested by one or more teachers were as follows:

1. Lighting birthday candles.
2. A cookout or hot dog roast during a visit to a city park or available forest picnic area, a barbecue at the home of one of the children, and cooking experience in the classroom.
3. Burning incense.
4. Taking children outside and showing them the danger of throwing matches, cigarettes, etc., on dry grass.
5. Outside experiments on the effectiveness of dirt, water, blowing, etc., in putting out a fire.
6. Melting candles and crayons in preparation for craft projects.
7. Visiting a city dump at trash burning time.

Not all teachers accepted the idea of providing fire positive activities. They felt, instead, that the emphasis should be on teaching children to avoid stoves, heaters, and other sources of burn injury. A few felt that it would be setting a bad example for the teacher to light matches and to conduct fire experiments. Several reported that school and fire department rules precluded fire experimentation.

Other supplementary activities suggested for this unit were the following:

1. Learn to dial "operator" on telephone to report a fire.
2. Learn how to put out a fire on clothing.
3. Have a fire drill.
4. Arrange for a visit from Smokey.
5. Paint, or finger paint, flame shapes.
6. Make a red fire truck.
7. Dramatic play with blocks, enacting firemen putting out a fire.
8. Make play dough cakes with candles.

### Unit C. Fire Prevention

The objectives of the unit on fire prevention, were to teach Headstart children (1) to use fire properly, (2) to recognize fire hazards and eliminate them, and (3) to accept the responsibility of preventing fires. Much of the unit is devoted to the concept of National Fire Prevention Week and its commemoration of the Chicago fire of 1871. (This would seem to be extraneous to the stated objectives of the unit and of the total program.)

Pictures 44c-14, 15, and 16 showing children happily engaged in disapproved behavior with fire may be more effective in teaching the pleasure of such activity than poster 44c-17 is in teaching the unpleasant consequences.

The teacher's information leaflet points out the prevalent causes of fire, but contains no suggestions as to how this information and other materials in the folder might be used in achieving the objective of the unit.

The reaction to this unit was generally positive. The children were, on the whole, reportedly attentive and interested. From the teachers' comments it was evident that more emphasis should be given to specific things families can do to prevent fires, and that illustrations of unsafe fire behavior be eliminated.

Comments on the handouts for parents were diversified. Some teachers felt there were too many different ones; others that there were not enough. Many complained that certain ones were inappropriate for their particular area. It was apparent that many difficulties with the handouts would be removed if teachers understood that they were not necessarily expected to use all of the examples provided, but were to select those appropriate to their situation. It was also apparent that some teachers were not particularly aware of existing fire hazards, or that they shared the feelings of parents who felt powerless to effect changes.

Some teachers expressed a need for additional handouts covering such areas as trash cleanup in garage, house, and yard; cooking hazards (splattering grease, curtains near stove, etc.); defective wiring of stoves and appliances; defective electrical cords; etc. Handouts covering accident prevention materials in addition to fire prevention (for example, keeping medicines and poisonous substances out of reach of children) were also desired.

On the coloring books featuring Sniff and Snuff, there was a general feeling that the figures were too small and complex for preschool children. A few teachers felt that Sniff and Snuff unnecessarily confused the fire prevention program, and that one symbol of fire prevention, Smokey Bear, was enough.

### Unit D. Introduction to Smokey

The content of folder D sought (1) to help children recognize Smokey as the symbol of forest fire prevention, (2) to make them aware that Smokey knows what he is talking about (from personal experience?), and (3) to make children realize all people should follow Smokey's rules.

The picture materials are a simplified version of the story of Smokey Bear. Smokey is presented as a model from which positive attitudes toward fire may be established. This unit contains a letter for parents informing them of their child's having learned the story of Smokey and giving specific ways in which the parents can reinforce the lesson.

The teachers reported overwhelming enthusiasm for Smokey Bear and his story. Even 3-year-olds enter school knowing Smokey. Many supplementary activities were used or suggested for this unit:

1. Hand puppets made of picture of Smokey glued to small brown paper bags.
2. Stickers used to make posters.
3. Collages of Smokey. Yarn pasted on picture for fur; beads, buttons, or marbles for eyes, fabric or paper hat.
4. Other bear stories, and Smokey story on flannelboard.
5. Door poster collage of Smokey made out of cardboard on which children glued fabric pieces to make mosaic pants.
6. "I Help Smokey" folders made for color sheets.
7. Teddy bear brought to school and dressed as Smokey.
8. Trip to airport to see real jet (like one that transported Smokey).
9. Golden Book of Smokey the Bear.
10. Construction paper pictures of Smokey and forest in box lids. Children tore and pasted leaves. Trunks were made of brown colored soap and water foam (could also use flour, salt and water dough). Bear pictures were dittoed and colored by the children.
11. Stickers mounted on cardboard, placed on tinker toy standards and used in forest diorama.

Criticisms of the illustrations of the Smokey story, FPE 44d 2-11, were limited. However, a few teachers thought that the language and content could be simplified even further for young children.

### Unit E. Christmas

The Christmas folder sought to strengthen the Smokey Bear fire prevention image and remind parents and children of special holiday fire hazards.

Because the kit was not distributed until January, this unit received little use. Some teachers distributed the ash trays at parent meetings or sent them home with the children on the last day of school. Several teachers objected to their distribution because it would seem to indicate that the Division of Forestry and Headstart sanctioned smoking. It was suggested that they might better be utilized as molds for making painted clay or plaster paperweights.

### Unit F. Conservation

The objective of the Conservation Unit was to teach Headstart students that (1) natural resources (especially trees) are good, necessary and useful, (2) natural resources must be protected from fire, and (3) many years are required to replace a forest destroyed by fire.

The series of 12 illustrations demonstrate that there are different kinds of trees and they provide different benefits to man. The effect of fire on trees and the necessity of protecting them from fire are also stressed, along with the importance of replanting areas where trees have been destroyed or used.

The teacher information leaflet suggests that the

class might participate in an Arbor Day celebration or other tree planting experience.

Although several teachers found this unit interesting to the children, a few reported it boring. Less time and fewer sessions were spent on this unit than on any other except the Christmas unit (*table 6* in Appendix). This unit may have suffered more than the others from the delay in reaching the classrooms. In this area, fall would have been a better time for tree planting. The unit's position next to last in the kit may also have influenced its use. Teachers showed considerable interest, however, in developing follow-up activities–visits to building sites or lumber yards to see different kinds of wood and collect scraps for use in class; trip to friend's yard to pick oranges from tree, stressing "trees give us food"; collecting pictures of objects made of wood; and so forth.

A few teachers reported that the concept of the time required to grow a tree was too difficult for the children. They also found the unit poster, How a Tree Grows, far beyond the children's comprehension. Teachers seemed at a loss as to how to use it. It probably should be greatly simplified or eliminated.

### Unit G. Smart Cookie–Dumb Cookie

The objectives of this unit as stated, were to teach Headstart children that (1) they must follow safety rules in order to be protected, (2) life can be very unpleasant if rules are not known or not followed, and (3) playing with matches and experimenting with fire without parental supervision is very dangerous.

Fire prevention is developed as a part of general safety in this unit. The actions of a positive model (a stick character with a smiling cookie for a head named Smart Cookie) are contrasted with a negative model (Dumb Cookie) in a number of potentially unsafe situations. The expectation is that children will identify with the positive model. Adhesive-backed "Smart Cookies" are provided for the children to wear to reinforce this concept.

Resource people generally and a few teachers felt that the negative model "Dumb Cookie" was inappropriate; most teachers felt that it was extremely effective. Next to the Smokey Bear unit, this was the most popular unit, judging from the interview and narrative comments and from the amount of time allotted to it. Although most teachers approved the inclusion of a broad span of accident prevention material, a few objected to this, preferring a focus on fire prevention.

Reasons given for the success of the unit were the simplicity of the stick figures and the use of a clear-cut model (Smart Cookie) with whom the children could readily identify. The teachers who approved the use of "Dumb Cookie" felt that children clearly did not choose him as a model. In several instances, however, children identified others with "Dumb Cookie," and this was the type of behavior that was considered undesirable by those who opposed use of the negative model.

All teachers who commented reported the children enthusiastic about the adhesive-backed "Smart Cookies" provided each child.

## SUMMARY AND CONCLUSIONS

Folkman, William S., and Jean Taylor.
1972. **Fire prevention in California's Riverside County Headstart Project. . .an evaluation.** Berkeley, Calif., Pacific SW. Forest & Range Exp. Sta. 29 p. (USDA Forest Service Res. Paper PSW-79)

*Oxford:* 431.3–094.8:432.14–01.
*Retrieval Terms:* forest fire prevention programs; fire prevention education; children-with-matches-fires; Headstart Project.

An especially designed series of fire prevention lessons were taught to preschool children in the Headstart Project in Riverside County, California. The lessons, with related educational materials, were developed by the California Division of Forestry and by a committee of Headstart Project teachers. Teachers in one-half of the classes in the county used these lessons during the 1968-1969 school year. The effectiveness of these materials was evaluated by the fire prevention research unit of the Pacific Southwest Forest and Range Experiment Station. Evaluation included observing classroom reaction and testing children at the end of the year.

This evaluation of an experimental fire prevention

education program conducted with Riverside Headstart children documents the feasibility of this type of educational approach with preschool children. The findings do not suggest that this, alone, is the solution to the serious and growing problem of child-caused fires. Children's natural fascination with fire, the general pervasiveness of fire use in our society, and the conceptual maturity of this age level make such efforts only a beginning step in a continuing process of education in the individual's relation to his environment. Ideally, this should extend through a lifetime.

The tests and observations reveal both strengths and weaknesses in the program materials as presently developed. These are documented in the body of this report. The response of the Riverside Headstart teachers to the materials and the intense interest in them shown in educational circles throughout the country testify to a growing awareness of the problem and to the paucity of available materials to meet it.

The Headstart kit was most successful in meeting the cognitive goals of the program. That is, improvements were observed in the children's understanding of certain cause-and-effect relationships concerning fire behavior. Positive changes in curiosity about fire and attitudes toward fire were less apparent. Modifications in the materials or, more importantly, in the instructions for their use, and the addition of suggestions for enrichment activities related to them, appear likely to improve materially goal achievement possibilities. Specific examples are detailed in the report. The main effect of these suggestions would be to involve the children in meaningful activities rather than rely so heavily on verbal transmission of information.

In the opinion of the evaluators, the format of the materials provided encouraged an aural-visual type of teaching method. For young children particularly, this method is relatively ineffective, even for cognative concepts. To achieve the goals of satisfying curiosity and changing attitude, active learning through experience is undoubtedly necessary.

The assumption apparently made by the planners of the program that teachers, as professional educators, would know how to adapt the materials provided and extend them into effective learning situations is not warranted. In Unit B, Introduction to Fire, for example, even the most innovative teacher would benefit from detailed suggestions on how to carry out meaningful and satisfying fire experiences for the children, including specific precautions to be observed.

The problem of how to expose children to fire safely has not been satisfactorily solved, but experiences with fire seem essential to genuine satisfaction of the child's curiosity. Most teachers would prefer to leave this responsibility to the parents, and this may be wise, but the fire prevention implications of permissible classroom activities using fire (or heat), such as cooking and birthday candles, are not exploited as fully as they might be.

Most of the units would benefit from the inclusion of a letter to parents similar to the one in Unit D, Introduction to Smokey. Such a letter, explaining in general what the children have been learning, and specific suggestions on how parents might supplement or reinforce this learning, would probably increase the effectiveness of the program. Parents would be much more apt to provide the desired positive models of fire-use behavior with such assistance, especially if this were preceded by an explanation of the total program at an early parent-teacher meeting.

The momentum of this initial effort should not be lost. Further experimentation and modification is needed, but much can be done in an ongoing program provided with built-in evaluation procedures.

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# APPENDIX

## *Tables*

ble 1—*Characteristics of Headstart children in experimen- l and control classes*[1]

| Characteristic | Experimental classes (n=512) | Control classes (n=430) |
|---|---|---|
| | *Percent* | |
| nic origin:[2] | | |
| egro | 21 | 22 |
| lexican-American | 44 | 45 |
| ther Caucasian | 21 | 14 |
| merican Indian | 2 | 3 |
| ther | 4 | 2 |
| ot reported | 8 | 14 |
| Total | 100 | 100 |
| e: | | |
| years and over | 2 | 1 |
| | 37 | 32 |
| | 40 | 42 |
| Inder 4 years | 5 | 5 |
| lot reported | 16 | 20 |
| Total | 100 | 100 |
| mily income:[3] | | |
| bove EOB poverty level | 24 | 25 |
| 0 - 499 below | 14 | 14 |
| 500 - 1499 below | 29 | 22 |
| 1,500 - or more below | 11 | 17 |
| lot reported | 22 | 22 |
| Total | 100 | 100 |
| x: | | |
| Iale | 45 | 49 |
| emale | 49 | 46 |
| lot reported | 6 | 5 |
| Total | 100 | 100 |
| ild speaks English: | | |
| es | 84 | 79 |
| o | 8 | 11 |
| lot reported | 8 | 10 |
| Total | 100 | 100 |
| mily now on welfare:[4] | | |
| es | 45 | 39 |
| o | 42 | 43 |
| lot reported | 13 | 18 |
| Total | 100 | 100 |

ata from records of Economic Opportunity Board.

ifferences between experimental and control classes atistically significant at the following level of probably, by i-square test:

percent level.

percent level.

percent level.

Table 2—*Test results of Headstart children in experimental and control classes*

| Test form | Experimental classes | | | Control classes | | |
|---|---|---|---|---|---|---|
| | No. of tests | Mean score | Standard deviation | No. of tests | Mean score | Standard deviation |
| Conceptual items | | | | | | |
| Pictorial Section: | | | | | | |
| Form A | 187 | 49.2 | 18.0 | 160 | 44.5 | 16.4 |
| Form B | 174 | 44.0 | 17.8 | 142 | 39.5 | 17.1 |
| Form C | 151 | 51.3 | 19.0 | 132 | 43.8 | 19.1 |
| Oral Section: | | | | | | |
| Form A | 186 | 62.5 | 15.9 | 151 | 57.1 | 17.0 |
| Form B | 164 | 63.0 | 15.8 | 137 | 56.2 | 17.2 |
| Form C | 145 | 50.3 | 16.4 | 130 | 46.9 | 16.4 |
| Affective items | | | | | | |
| Pictorial Section: | | | | | | |
| Form A | 187 | 37.4 | 20.8 | 160 | 33.7 | 21.5 |
| Form B | 174 | 38.5 | 23.9 | 142 | 38.4 | 24.2 |
| Form C | 151 | 36.8 | 21.4 | 132 | 35.6 | 22.3 |
| Oral Section: | | | | | | |
| Form A | 186 | 25.8 | 21.9 | 151 | 29.5 | 21.7 |
| Form B | 164 | 41.9 | 27.1 | 137 | 40.6 | 28.8 |
| Form C | 145 | 46.1 | 26.7 | 130 | 48.0 | 24.6 |

Table 3—*Test scores of experimental and control classes by age group*

| Test score[1] | Five or more years | | Under five years | |
|---|---|---|---|---|
| | Experimental classes | Control classes | Experimental classes | Control classes |
| | *Percent* | | | |
| Pictorial Section: | | | | |
| 61-100 | 33 | 21 | 12 | 11 |
| 31-60 | 52 | 51 | 68 | 69 |
| 0-30 | 15 | 28 | 20 | 20 |
| Total | 100 | 100 | 100 | 100 |
| Mean Score | 51.0 | 44.6** | 43.4 | 40.2 |
| Oral Section: | | | | |
| 61-100 | 64 | 48 | 55 | 43 |
| 31-60 | 31 | 46 | 39 | 47 |
| 0-30 | 5 | 6 | 6 | 10 |
| Total | 100 | 100 | 100 | 100 |
| Mean Score | 61.3 | 55.5** | 57.7 | 52.6* |

[1]Forms A, B, and C combined.

**Differences between experimental and control classes statistically significant at 2 percent level of probability by chi-square test.

*Differences between experimental and control classes statistically significant at 5 percent level of probability by chi-square test.

Table 4—*Response of children in experimental and control classes to individual items in the various forms of the pictorial test*

| Item | Form A | | | Form B | | | Form C | | |
|---|---|---|---|---|---|---|---|---|---|
| | Exp. (n=186) | Cont. (n=160) | Dif. | Exp. (n=171) | Cont. (n=142) | Dif. | Exp. (n=150) | Cont. (n=132) | Dif. |
| | *Percent* | | | | | | | | |
| 1[1] | 35.6 | 33.5 | 2.1 | 60.8 | 52.1 | 8.7 | 64.7 | 59.8 | 4.9 |
| 2 | 55.8 | 43.0 | 12.8** | 78.9 | 74.6 | 4.3 | 68.0 | 62.9 | 5.1 |
| 3 | 43.6 | 46.8 | -3.2 | 32.7 | 26.8 | 5.9 | 66.7 | 73.5 | -6.8 |
| 4 | 35.6 | 35.4 | .2 | 45.0 | 51.4 | -6.4 | 46.6 | 37.1 | 9.5 |
| 5 | 18.6 | 15.9 | 2.7 | 16.4 | 17.6 | -1.2 | 14.7 | 14.4 | .3 |
| 6 | 50.5 | 53.2 | -2.7 | 52.6 | 49.3 | 3.3 | 60.0 | 59.1 | .3 |
| 7 | 85.6 | 81.0 | 4.6 | 28.6 | 30.3 | -1.7 | 23.3 | 15.9 | 7.4 |
| 8 | 44.1 | 51.2 | -7.2 | 56.1 | 45.1 | 11.0* | 64.7 | 47.7 | 17.0** |
| 9[1] | 40.4 | 39.9 | .5 | 45.0 | 42.2 | 2.8 | 32.7 | 34.8 | -2.1 |
| 10[1] | 52.6 | 46.8 | 5.8 | 35.7 | 34.5 | 1.2 | 18.6 | 18.2 | .4 |
| 11 | 21.8 | 13.3 | 8.5* | 28.1 | 16.9 | 11.2* | 53.3 | 42.4 | 10.9 |
| 12 | 51.0 | 44.3 | 6.7 | 43.3 | 35.2 | 8.1 | 36.7 | 28.8 | 7.9 |
| 13[1] | 24.5 | 23.4 | 1.1 | 19.9 | 26.1 | -6.2 | 34.7 | 24.2 | 10.5 |
| 14 | 54.2 | 46.2 | 8.0 | 22.8 | 23.2 | - .4 | 64.7 | 48.5 | 16.2** |
| 15 | 55.8 | 53.2 | 2.6 | 54.4 | 50.0 | 4.4 | 56.0 | 50.0 | 6.0 |
| 16 | 55.3 | 47.5 | 7.8 | 56.7 | 43.7 | 13.0* | 44.7 | 32.6 | 12.1* |
| 17 | 45.7 | 30.4 | 15.3*** | 88.3 | 76.1 | 12.2* | 71.3 | 59.1 | 12.2* |
| 18 | 76.6 | 72.2 | 4.4 | 33.9 | 26.8 | 7.1 | 64.0 | 59.1 | 4.9 |
| 19 | 39.9 | 42.4 | -2.5 | 28.7 | 25.4 | 3.3 | 40.0 | 25.8 | 14.2** |
| 20[1] | 33.0 | 27.2 | 5.8 | 34.5 | 37.3 | -2.8 | 34.7 | 40.9 | -6.2 |

[1]Affect item: fire positive answer reported.
*Statistically significant at 5 percent level by chi-square test.
**Statistically significant at 2 percent level by chi-square test.
***Statistically significant at 1 percent level by chi-square test.

Table 5—*Response of children in experiment and control classes to individual items in the various forms of the oral test*

| Item | Form A | | | Form B | | | Form C | | |
|---|---|---|---|---|---|---|---|---|---|
| | Exp. (n=185) | Cont. (n=151) | Dif. | Exp. (n=162) | Cont. (n=137) | Dif. | Exp. (n=143) | Cont. (n=130) | Dif. |
| | *Percent* | | | | | | | | |
| 1 | 48 | 36 | 12* | 91 | 86 | 5 | 41 | 48 | -7 |
| 2 | 52 | 46 | 6 | 51 | 43 | 8 | 75 | 62 | 13** |
| 3 | 51 | 45 | 6 | 74 | 58 | 16*** | 32 | 31 | 1 |
| 4 | 55 | 50 | 5 | 75 | 64 | 11* | 54 | 52 | 2 |
| 5 | 36 | 38 | -2 | 34 | 27 | 7 | 25 | 25 | 0 |
| 6 | 64 | 54 | 10 | 86 | 80 | 6 | 71 | 63 | 8 |
| 7 | 82 | 79 | 3 | 90 | 82 | 8 | 39 | 25 | 13** |
| 8 | 75 | 73 | 2 | 79 | 66 | 13** | 75 | 73 | 2 |
| 9 | 67 | 59 | 8 | 72 | 68 | 4 | 31 | 42 | -11 |
| 10 | 81 | 75 | 6 | 81 | 78 | 3 | 51 | 39 | 12* |
| 11 | 79 | 70 | 9 | 31 | 34 | -3 | 43 | 40 | 3 |
| 12 | 52 | 43 | 9 | 56 | 52 | 4 | 53 | 53 | 0 |
| 13 | 83 | 80 | 3 | 70 | 66 | 4 | 75 | 71 | 4 |
| 14[1] | 31 | 41 | -10 | 9 | 8 | 1 | 47 | 45 | 2 |
| 15[2] | 70 | 70 | 0 | 67 | 74 | -7 | 59 | 60 | -1 |
| 16[1] | 12 | 16 | 4 | 64 | 64 | 0 | 63 | 65 | -2 |
| 17[2] | 20 | 24 | 4 | 23 | 27 | -3 | 31 | 32 | -1 |
| 18[1] | 42 | 42 | 0 | 48 | 46 | 2 | 45 | 48 | -3 |
| 19 | 82 | 72 | 10 | 43 | 39 | 4 | 37 | 28 | 9 |
| 20 | 70 | 64 | 6 | 73 | 61 | 12* | 24 | 24 | 0 |
| 21 | 58 | 55 | 3 | 58 | 47 | 11 | 57 | 61 | -4 |
| 22[1] | 10 | 15 | -5 | 42 | 44 | -2 | 57 | 63 | -6 |
| 23 | 20 | 22 | -2 | 71 | 66 | 5 | 62 | 52 | 10 |
| 24 | 69 | 66 | 3 | 79 | 66 | 13** | 59 | 56 | 3 |
| 25[1] | 32 | 36 | -4 | 47 | 42 | 4 | 16 | 20 | -4 |

[1]Affect item, fire positive answer reported.
[2]Fire experience, affirmative response.
*Statistically significant at 5 percent level by chi-square test.
**Statistically significant at 2 percent level by chi-square test.
***Statistically significant at 1 percent level by chi-square test.

Table 6–*Frequency and duration of use by teachers of units in fire prevention kits*[1]

| Item | Unit B | Unit C | Unit D | Unit F | Unit G |
|---|---|---|---|---|---|
| Teachers reporting ..... No. | 33 | 28 | 30 | 29 | 28 |
| Lessons given ..... No. | 83 | 65 | 94 | 57 | 68 |
| Average lessons for teacher reporting ..... No. | 2.5 | 2.3 | 3.1 | 2 | 2.4 |
| Teachers using unit: | | | | | |
| Once ..... No./Pct. | 9 (27.3) | 8 (28.6) | 5 (17.7) | 17 (58.6) | 12 (42.9) |
| Twice ..... No./Pct. | 10 (30.3) | 9 (32.2) | 10 (33.3) | 5 (17.3) | 4 (14.3) |
| Three times ..... No./Pct. | 5 (15.2) | 6 (23.1) | 2 (6.7) | 2 (6.9) | 5 (18) |
| Four times ..... No./Pct. | 7 (21.2) | 4 (14.3) | 10 (33.3) | 1 (3.4) | 3 (10.6) |
| Five or more times .... No./Pct. | 2 (6) | 1 (3.6) | 3 (10) | 4 (13.8) | 4 (14.2) |
| Lessons lasting: | | | | | |
| 60 minutes ..... No./Pct. | 3 (3.6) | 3 (4.5) | 6 (6.4) | 5 (8.8) | 5 (7.5) |
| 45 minutes ..... No./Pct. | 4 (4.8) | 2 (3.1) | 2 (2.2) | 4 (7) | 4 (5.7) |
| 30 minutes ..... No./Pct. | 32 (38.6) | 30 (46.2) | 24 (25.5) | 20 (25.1) | 33 (48.4) |
| 15 or 20 minutes ..... No./Pct. | 44 (53) | 30 (46.2) | 62 (65.9) | 28 (49.1) | 26 (38.4) |
| Average duration of lesson ..... Min. | 24.2 | 24.5 | 22.3 | 26.4 | 28 |
| Average total time spent on lesson for teacher reporting ..... Min. | 61 | 57 | 70 | 52 | 68 |

[1]Units A (Teacher Information) and E (Christmas) not included in tabulation. Unit B is Introduction to Fire; C-Fire Prevention; D-Introduction to Smokey Bear; F-Conservation; and G-Smart Cookie–Dumb Cookie.

able 7–*Manner of use by teachers of material from units in fire prevention kit*[1]

| Item | Unit B | | Unit C | | Unit D | | Unit F | | Unit G | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *No.* | *Pct.* | *No.* | *Pct.* | *No.* | *Pct.* | *No.* | *Pct.* | *No.* | *Pct.* |
| essons in which: | | | | | | | | | | |
| All material was used | 55 | 66.1 | 41 | 63.1 | 48 | 52.1 | 42 | 73.7 | 60 | 88.2 |
| Part of material was used | 28 | 33.7 | 24 | 36.9 | 46 | 47.9 | 15 | 26.3 | 8 | 11.8 |
| eachers who: | | | | | | | | | | |
| Worked directly from prepared materials | 12 | 36.4 | 8 | 28.6 | 8 | 26.7 | 12 | 41.5 | 8 | 28.6 |
| Used own materials to supplement prepared material | 17 | 51.5 | 12 | 46.4 | 11 | 36.7 | 14 | 48.2 | 14 | 50.0 |
| Used prepared materials as resource only | 0 | .0 | 0 | .0 | 1 | 3.3 | 0 | .0 | 1 | 3.6 |
| Used prepared material for display only (lessons based on own materials) | 1 | 3.0 | 1 | 3.6 | 0 | .0 | 0 | .0 | 0 | .0 |
| Did not check or report more than one | 3 | 9.1 | 7 | 25 | 10 | 33.3 | 3 | 10.3 | 5 | 17.8 |
| eachers using supplemental materials or activities: | | | | | | | | | | |
| Films | 4 | 12.1 | 2 | 7.2 | 9 | 30.0 | 3 | 10.3 | 1 | 3.6 |
| Phonograph records | 4 | 12.1 | 3 | 10.8 | 17 | 56.7 | 2 | 6.9 | 1 | 3.6 |
| Posters | 18 | 54.5 | 18 | 64.6 | 19 | 63.3 | 19 | 65.5 | 14 | 50.0 |
| Field trip to forestry station | 1 | 3.0 | 1 | 3.6 | 1 | 3.3 | 1 | 3.4 | 0 | .0 |
| Field trip to fire station | 3 | 9.1 | 0 | .0 | 2 | 6.7 | 0 | .0 | 0 | .0 |
| Cookout with fire-making experiment | 0 | .0 | 0 | .0 | 1 | 3.3 | 0 | .0 | 1 | 3.6 |
| Controlled fire experiment | 8 | 24.3 | 2 | 7.2 | 1 | 3.3 | 0 | .0 | 0 | .0 |
| Cooking lesson, fire control explained | 1 | 3.0 | 1 | 3.6 | 1 | 3.3 | 0 | .0 | 4 | 14.3 |
| Color sheets: | | | | | | | | | | |
| Used | 24 | 22.7 | 25 | 89.3 | 23 | 76.7 | 14 | 48.3 | 12 | 42.8 |
| Sent home | 17 | 51.5 | 17 | 60.7 | 17 | 56.7 | 9 | 31.0 | 13 | 46.4 |

[1]Units A (Teacher Information) and E (Christmas) not included in tabulation. Unit B is ntroduction to Fire; C-Fire Prevention; D-Introduction to Smokey Bear; F-Conservation; and G-Smart Cookie–Dumb Cookie.

Table 8–*Response of teachers of experimental classes to the units of the fire prevention kit*[1]

| Questions | Answers by number and percent of teachers responding | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Unit B | | Unit C | | Unit D | | Unit F | | Unit G | |
| | *No.* | *Pct.* | *No.* | *Pct.* | *No.* | *Pct.* | *No.* | *Pct.* | *No.* | *Pct.* |
| Do you think this unit is a desirable addition to the regular curriculum? | | | | | | | | | | |
| Yes . . . . . | 24 | 96.0 | 22 | 100.0 | 24 | 96.0 | 24 | 96.0 | 22 | 100.0 |
| No . . . . . | 0 | .0 | 0 | .0 | 1 | 4.0 | 1 | 4.0 | 0 | .0 |
| Undecided . . . . | 1 | 4.0 | 0 | .0 | 0 | .0 | 0 | .0 | 0 | .0 |
| Total | 25 | 100.0 | 22 | 100.0 | 25 | 100.0 | 25 | 100.0 | 22 | 100.0 |
| Do you think the children's behavior will change as a result of this unit? | | | | | | | | | | |
| Yes . . . . . | 24 | 92.3 | 22 | 95.7 | 24 | 100.0 | 20 | 87.0 | 22 | 95.7 |
| No . . . . . | 0 | .0 | 0 | .0 | 0 | .0 | 1 | 4.3 | 0 | .0 |
| Undecided . . . . | 2 | 7.7 | 1 | 4.3 | 0 | .0 | 2 | 8.7 | 1 | 4.3 |
| Total | 26 | 100.0 | 23 | 100.0 | 24 | 100.0 | 23 | 100.0 | 23 | 100.0 |
| Would you like to give it again next year? | | | | | | | | | | |
| Yes . . . . . | 25 | 100.0 | 23 | 95.8 | 25 | 96.1 | 23 | 95.8 | 22 | 100.0 |
| No . . . . . | 0 | .0 | 1 | 4.2 | 1 | 3.9 | 1 | 4.2 | 0 | .0 |
| Undecided . . . . | 0 | .0 | 0 | .0 | 0 | .0 | 0 | .0 | 0 | .0 |
| Total | 25 | 100.0 | 24 | 100.0 | 26 | 100.0 | 24 | 100.0 | 22 | 100.0 |

[1]Units A (Teacher Information) and E (Christmas) not included in tabulation. Unit B is Introduction to Fire: C-Fire Prevention; D-Introduction to Smokey Bear; F-Conservation; and G-Smart Cookie–Dumb Cookie.

# Tests

PICTORIAL TEST

FORM A - SELECTION ITEMS (BLUE BOOKLET)

(PINK) LP

1. Juan and Pedro went on a camping trip. (POINT) Juan helps his father build a fire and (POINT) Pedro helps his father catch fish. Which would you like to do?

1. Juan y Pedro fueron a campar. (POINT) Juan le ayuda a su padre hacer fuego y (POINT) Pedro le ayuda a su padre a pescar. ¿A tí qué te gustaría hacer?

(GREEN)

2. Point to the bottle that has poison in it.

2. ¿Cuál es la botella que tiene veneno?

(YELLOW)

3. (POINT) This man builds a fire near his car. (POINT) This man builds a fire in a special fire pit. (POINT) This man builds a fire in an open space near some twigs. Point to the picture that shows the man lighting a campfire in the best place.

3. ( POINT) Este hombre hace un fuego cerca de su carro. (POINT) Este hombre hace un fuego en un lugar especial para hacer fuegos. (POINT) Este hombre hace un fuego en un lugar abierto cerca de unas ramitas. ¿Cuál es el hombre que está haciendo un fuego en el mejor lugar?

(BLUE)

4. (POINT) This girl is cutting bread by herself. (POINT) This girl takes the knife and bread to her mother for cutting. (POINT) This girl takes the bread to her mother. Which is the right thing to do?

4. (POINT) Esta niña está cortando el pan solita. (POINT) Esta chica le da el cuchillo y el pan a su mamá para que lo corte. (POINT) Esta niña le lleva el pan a su mamá. ¿Qué es lo que tú debes hacer?

(WHITE)

5. (POINT) Here is fire on the kitchen stove. (POINT) Here are some towels near a heater. (POINT) Here is fire in a barbeque. Which picture shows the place for a bad fire to start?

5. (POINT) Aquí hay un fuego en la estufa de la cocina. (POINT) Aquí hay algunas toallas cerca del calentador. (POINT) Aquí hay un fuego en la barbacoa. ¿ Cuál es el cuadro que muestra el lugar donde puede comenzar un incendio peligroso?

(PINK)

6. (POINT) This boy crosses the street without waiting for the light to change to green. (POINT) This boy waits for the green light. (POINT) This boy chases a ball into the street. Point to the right thing to do.

6. (POINT) Este chico atraviesa la calle sin esperar que la luz roja cambie a la verde. (POINT) Este chico espera a la luz verde. (POINT) Este chico atraviesa la calle corriendo tras una pelota. ¿ Qué es lo que tú debes hacer?

(GREEN)

7. (POINT) This is a ranger. (POINT) This is a policeman. (POINT) This is a fireman. Point to the one who puts out fires in the city.

7. (POINT) Este es un guardiabosques. (POINT) Este es un policía (POINT) Este es un bombero. ¿Cuál es el que apaga los incendios en la ciudad?

(YELLOW) 8. (POINT) This lady throws the match on the ground. (POINT) This one puts water on the match. (POINT) This one blows it out. Point to the picture that shows where a bad fire may start.

8. (POINT) Esta señora tira el fósforo al suelo. (POINT) Esta le pone agua encima. (POINT) Esta lo sopla. ¿Adónde puede comenzar un incendio peligroso?

(BLUE) LP 9. (POINT) Angela likes to play fireman with the boys. (POINT) Carmen likes to play ball with the boys. Which would you like to do?

9. (POINT) A Ángela le gusta jugar a los bomberos con los muchachos. (POINT) A Carmen le gusta jugar a la pelota con los muchachos. ¿A tí qué te gustaría hacer?

(WHITE) LP 10. (POINT) These children are watching the man put out a fire. (POINT) These children are watching the man fix the street. Which would you like to do?

10. (POINT) Estos niños miran a los hombres que estan apagando el incendio. (POINT) Estos niños miran a los hombres que están arreglando la calle. ¿A tí qué te gustaría hacer?

(PINK) 11. (POINT) Here are some old rags and trash near a gas can. (POINT) Here is a fireplace. (POINT) Here is a kitchen stove. Point to the picture that shows where a bad fire may start.

11. (POINT) Aquí hay unos trapos, basura y una lata de gasolina. (POINT) Aquí hay una chimenea. (POINT) Aquí hay una estufa. ¿Adónde puede empezar un incendio peligroso?

(GREEN) 12. Point to the thing that is specially made to put out fires in big buildings.

12. ¿Cuál es la cosa especial que apaga incendios en los edificios grandes?

(YELLOW) RP 13. (POINT) Here the children are playing with water. (POINT) Here they are playing with fire. Point to the picture that shows what you like to do.

13. (POINT) Aquí los ninos estan jugando con agua. (POINT) Aquí estan jugando con fuego. ¿A tí qué te gustaría hacer?

(BLUE) 14. (POINT) This girl puts the campfire out with water. (POINT) This girl throws papers on the fire. (POINT) This girl had a picnic and left all the papers and trash under the tree. Point to the girl who is doing the right thing.

14. (POINT) Esta muchacha apaga el fuego de campamento con agua. (POINT) Esta muchacha echa papeles en el fuego. (POINT) Esta nina estuvo de picnic y dejó todos los papeles y la basura debajo del árbol. ¿Cuál es la nina que hace lo que se debe hacer?

(WHITE) 15. Maria's mommy told her to stir the soup. (POINT) Here she tries to reach it from the floor. (POINT) Here she stands on a broken box. (POINT) Here she stands on a chair. Point to the picture that shows the best way for her to do it.

15. La mamá de María le dijo que revolviera la sopa. (POINT) Aquí trata de alcanzar la sopa desde el suelo. (POINT) Aquí María se para sobre un cajon roto. (POINT) Aquí se para sobre una silla. ¿Cuál es la mejor manera de hacerlo?

(PINK) 16. (POINT) Here is a boy helping his father work with a fire torch. (POINT) Here is a boy playing with a burning stick. (POINT) Here is a boy helping his father build a fire in a barbeque pit. Point to the bad thing to do.

16. (POINT) Aquí está un niño que ayuda a su padre soldar con una antorcha. (POINT) Aquí un niño juega con una rama encendida. (POINT) Aquí un chico ayuda a su papá hacer un fuego en la barbacoa. ¿Cuál hace lo que no debe hacer?

(GREEN) 17. (POINT) Here is a forest. (POINT) Here is a desert. (POINT) Here is a seashore. Point to where Smokey lives.

17. (POINT) Aquí está un bosque. (POINT) Aquí está un desierto. (POINT) Aquí está una playa. ¿Adónde vive Smokey?

(YELLOW) 18. (POINT) Here are some children cloring in a book. (POINT) Here are some children playing jump rope. (POINT) Here are some children playing with matches. Point to the bad thing to do.

18. (POINT) Aquí unos chicos colorean en un libro. (POINT) Aquí otros chicos saltan con una cuerda. (POINT) Aquí los chicos juegan con unos fosforos. ¿Cuáles hacen lo que no se debe hacer?

(BLUE) 19. (POINT) This boy is throwing papers on a fire. (POINT) This boy is building a fire in the forest. (POINT) This boy is learning what fire can do. Point to the one who makes fire his friend.

19. (POINT) Este niño está tirando los papeles al fuego. (POINT) Este niño está haciendo un fuego en el bosque. (POINT) Este niño está aprendiendo para qué sirve el fuego. ¿Cuál es el que está haciendose amigo del fuego?

(WHITE) 20. (POINT) Here the children are using a fire torch to build something from metal. (POINT) Here the children are using a nail and hammer to build something from wood. What would you like to do?

20. Aquí los niños usan una antorcha para hacer cosas de metal. (POINT) Aquí los ninos usan un clavo y un martillo para hacer cosas de madera. ¿A tí qué te gustaría hacer?

## FORM B - SELECTION ITEMS (GREEN BOOKLET)

(PINK) RP 1. Maria and Juanita are helping their mother make tortillas. (POINT) Maria is frying them and Juanita is mixing the batter. Point to which you would like to do.

1. María y Juanita le estan ayudando a su mamá hacer tortillas. (POINT) María las está mezclando y (POINT) Juanita las está friendo. ¿A tí qué te gustaría hacer?

(GREEN) 2. Point to the one that is bad to drink.

2. ¿Cuál es la que no bebes beber?

(YELLOW) 3. We celebrate Fire Prevention Week because of a big fire started by one of these animals. Point to the animal that started the fire.

3. Celebramos la Semana de Prevención de Incendios, Fire Prevention Week, porque uno de estos animales hizo un incendio. ¿Cuál es el que comenzó el incendio?

(BLUE) 4. (POINT) Here is girl cutting out paperdolls by an open fire. (POINT) Here is a girl throwing papers on a fire. (POINT) Here is a boy sitting on a chair cutting out paperdolls. Point to the right thing to do.

4. (POINT) Aquí una niña corta muñecas de papel junto al fuego. (POINT) Aquí esta chica echa papeles en la chimenea. (POINT) Aquí un chico corta muñecas de papel sentado en una silla. ¿Cuál de estas cosas debes hacer tú?

(WHITE) 5. (POINT) Here is a fire burning in a fire pit. (POINT) Here are some leaves near a chimney. (POINT) Here is a fire burning in a barbeque. Point to the picture that shows the place a bad fire may start.

5. (POINT) Aquí hay un fuego de campamento. (POINT) Aquí hay algunas hojas cerca de la chimenea. (POINT) Aquí hay un fuego en la barbacoa. ¿Adonde puede comenzar un fuego peligroso?

(PINK) 6. (POINT) Here is a boy flying a kite. (POINT) Here is a boy running across the street between cars. (POINT) Here is a boy playing with fire. Which is the right thing to do?

6. (POINT) Aquí un chico juega con un papelote. (POINT) Aquí otro chico atravieza la calle corriendo entre dos coches. (POINT) Y este chico juéga con un fuego. ¿Qué es lo que tú debes hacer?

(GREEN) 7. (POINT) This is a ranger. (POINT) This is a policeman. (POINT) This is a fireman. Point to the man who saved Smokey.

7. (POINT) Este es un guardiabosques. (POINT) Este es un policía. (POINT) Este es un bombero. ¿Cuál salvó a Smokey?

(YELLOW) 8. (POINT) This is a fire burning a big building. (POINT) This is a fire in a fireplace. (POINT) This is a fire in a torch. Point to the bad fire.

8. (POINT) Este es un fuego en un edificio grande. (POINT) Este es un fuego en la chimenea. (POINT) Este es un fuego en una antorcha. ¿Cuál es el fuego malo y peligroso?

(BLUE) LP 9. When a house catches fire, (POINT) Manuel likes to stand and watch the firemen and (POINT) José runs home to his mother. What would you do if you saw a fire?

9. Cuando una casa se enciende, (POINT) a Manuel le gusta pararse y mirar a los bomberos. (POINT) José corre a casa donde está su mama. ¿Qué harías tú?

(WHITE) RP 10. (POINT) These children are coloring in a book. (POINT) These children are watching the fire in the fireplace. Which would you like to do?

10. (POINT) Estos niños están pintando en un libro de colores. (POINT) Estos niños están mirando al fuego en la chimenea. ¿A tí qué te gustaría hacer?

(PINK) 11. (POINT) Here is a fire burning on a stove. (POINT) Here is one electric plug in an outlet. (POINT) Here are many electric plugs in an outlet. Point to the picture that shows where a bad fire may start.

11. (POINT) Aquí hay un fuego en la estufa. (POINT) Aquí esta una clavija enchufada en la pared. (POINT) Aquí hay muchas clavijas enchufadas en la pared. ¿Adonde puede comenzar un fuego peligroso?

(GREEN) 12. Point to the fire extinguisher.

12. ¿Cuál es el extintor de incendios?

(YELLOW) LP 13. (POINT) These children are playing with matches. (POINT) These children are playing with marbles. Which would you like to do?

13. (POINT) Estos niños estan jugando con fósforos. (POINT) Estos ninos están jugando a las canicas. ¿A tí qué te gustaría hacer?

(BLUE) 14. (POINT) This boy saw a fire start in the forest and threw water on it. (POINT) This boy tells a grown-up about it. (POINT) This boy hides behind a tree and watches the fire burn. Point to the boy doing the right thing.

14. (POINT) Este niño vió un incendio en el bosque y le tiró agua. (POINT) Este niño se lo fué a contar a una persona grande. (POINT) Este niño se escondio detras de un árbol y miró al fuego encenderse. ¿Cual es el que hace lo que es correcto?

(WHITE) 15. (POINT) This lady throws the burning match on the ground. (POINT) This one throws the buring match into a trash can. (POINT) This one blows the burning match out. Point to the picture that shows the best way to put out the match.

15. (POINT) Esta señora tira el fósforo encendido al suelo. (POINT) Esta tira el fósforo encendido en la basura. (POINT) Esta sopla el fósforo encendido. ¿Cual es la mejor manera de apagar el fosforo?

(PINK) 16. (POINT) This girl throws water on a campfire. (POINT) This girl throws papers on a fire. (POINT) This girl is blowing the match out. Point to the bad thing to do.

16. (POINT) Esta muchacha le tira agua al fuego de campamento. (POINT) Esta muchacha tira papeles al fuego. (POINT) Esta niña esta apagando el fósforo a soplidos. ¿Qué cosa no debes hacer?

(GREEN) 17. Point to Smokey.

17. ¿Cual es Smokey?

(YELLOW) 18. (POINT) This lady is smoking in bed. (POINT) This lady is building a fire in the fireplace. (POINT) This lady is lighting candles on a birthday cake. Point to the bad thing to do.

18. (POINT) Esta señora fuma en la cama. (POINT) Esta señora hace fuego en la chimenea. (POINT) Esta señora prende las velitas del pastel. ¿Qué cosa no se debe hacer?

(BLUE) 19. (POINT) This is a fire on a stove. (POINT) This is a fire in a wastebasket. (POINT) This is a fire in a forest. Point to the picture that shows how fire can be our friend.

19. (POINT) Este es un fuego en la estufa. (POINT) Este es un fuego en la basura. (POINT) Este es un fuego en el bosque. ¿Cuál es el cuadro que muestra como el fuego puede ser nuestro amigo?

(WHITE) LP 20. (POINT) These children are cooking over a campfire. (POINT) These children are putting up a tent. Which would you like to do?

20. (POINT) Estos niños están cocinando en un fuego de campamento. (POINT) Estos niños están levantando una tienda de campaña. ¿A tí qué te gustaría hacer?

## FORM C - SELECTION ITEMS (YELLOW BOOKLET)

(PINK) RP 1. Sylvia and Rosita like to play house. (POINT) Sylvia takes care of the babies and (POINT)Rosita cooks the food. Point to which you would like to do.

1. A Silvia y a Rosita les gusta jugar a la casita. (POINT) Silvia cuida los niños y (POINT) Rosita cocina. ¿A tí qué te gustaría hacer?

(GREEN) 2. (POINT) This boy holds a grown-up's hand while crossing the street. (POINT) This boy runs across the street. (POINT) This boy waits for the green light. Point to the boy doing the bad thing.

2. (POINT) Este chico toma la mano de un grande al cruzar la calle. (POINT) Este chico cruza la calle corriendo. (POINT) Este chico espera que cambie la luz roja a la luz verde. ¿Cuál es el niño que hace lo que no debe hacer?

(YELLOW) 3. Point to the picture that shows what can happen to a boy when he plays with matches.

3. ¿Cuál es el cuadro que muestra lo que le puede pasar a un niño si juega con los fósforos?

(BLUE) 4. (POINT) This boy is pouring a drink of milk. (POINT) This boy is eating some pills. (POINT) This boy is pouring a drink from a bottle with this mark on it. Point to the right thing to do.

4. (POINT) Este chico toma leche. (POINT) Este se come unas pastillas. (POINT) Este chico vacía una botella marcada con este simbolo. ¿Qué cuadro muestra lo que se debe hacer?

(WHITE) 5. (POINT) Here is a fire burning on a stove. (POINT) Here is a fire burning in a fireplace. (POINT) Here are some curtains near a gas heater. Point to the picture that shows the place a bad fire may start

5. (POINT) Aquí hay fuego en la estufa. (POINT) Aquí hay fuego en la chimenea. (POINT) Aquí hay unas cortinas cerca del calentador de gaz ¿Adónde puede comenzar un incendio peligroso?

(PINK) 6. (POINT) This boy is riding his bike with "no hands". (POINT) This boy is riding with his hands on the handlebars. (POINT) These boys are riding double. Which is the right thing to do?

6. (POINT) Aquí un chico anda en su bicicleta sin manos. (POINT) Este chico anda en bicicleta con las manos en el manubrio. (POINT) Este chico lleva otro niño sobre el manubrio. ¿Cuál hace lo que debe hacer?

(GREEN) 7. (POINT) This is a ranger. (POINT) This is a policeman. (POINT) This is a fireman. Point to the man who takes care of the forest.

7. (POINT) Este es un guardiabosques. (POINT) Este es un policía. (POINT) Este es un bombero. ¿Quién es el que cuida los bosques?

(YELLOW) 8. (POINT) Here is a fire burning in a fireplace. (POINT) Here is a fire burning on a stove. (POINT) Here is a fire burning in a forest. Point to the picture that shows a bad fire.

8. (POINT) Aquí hay un fuego en la chimenea. (POINT) Aquí hay un fuego en la estufa. (POINT) Aquí hay un incendio en el bosque ¿Cuál es el fuego peligroso?

(BLUE) LP 9. Juan and Pedro were walking down the street when they heard a fire engine. (POINT) Juan got very excited and ran after the fire engine. (POINT) Pedro didn't like fires so he ran home. Which would you do?

9. Juan y Pedro caminaban por la calle cuando oyeron una bomba. (POINT) Juan se entusiasmó y corrió tras la bomba. (POINT) A Pedro no le gustaron los incendios y corrió a casa. ¿Qué harías tú?

(WHITE) LP 10. (POINT) Here the children are watching the fire burning in the fireplace. (POINT) Here the children are watching TV. Which would you like to do?

10. (POINT) Aquí los niños están mirando el fuego en la chimenea. (POINT) Aquí hay niños mirando la televisión. ¿A tí qué te gustaría hacer?

(PINK) 11. (POINT) Here is a gas can near a fire. (POINT) Here is a fire in a barbeque. (POINT) Here is a fire in the fireplace. Which picture shows the place a bad fire may start?

11. (POINT) Aquí hay una lata de gasolina cerca del fuego. (POINT) Aqui hay un fuego en la barbacoa. (POINT) Aqui hay un fuego en la chimenea. ¿Adónde puede comenzar un incendio peligroso?

(GREEN) 12. Which picture shows what you would use to let the fire station know there is a big fire?

12. ¿Qué cosa usarías para avisar a la estación de bomberos que hay un incendio grande?

(YELLOW) RP 13. (POINT) These children are playing in the sand. (POINT) These children are playing with matches. Which would you like to do?

13. (POINT) Estos niños están jugando en la arena. (POINT) Estos niños están jugando con fósforos. ¿A tí qué te gustaría hacer?

(BLUE) 14. (POINT) These children found some matches and played with them. These children gave the matches to a grown-up. (POINT) These children hid the matches in a drawer. Point to the children who are doing the right thing.

14. (POINT) Estos niños encontraron unos fósforos y jugaron con ellos. (POINT) Estos le dieron los fósforos a una persona grande. (POINT) Estos escondieron los fósforos en un cajón. ¿Cuales hacen lo que es bien?

(WHITE) 15. These boys were asked to clean up the papers in the yard. (POINT) Miguel put them in a trash can. (POINT) Pedro swept them into the street. (POINT) Juan put them in a burning incinerator. Which picture shows the best place to put the papers?

15. El papá de estos niños les pidió que quitaran los papeles del jardín. (POINT) Miguel los puso en un bote de basura. (POINT) Pedro los barrió hasta la calle. (POINT) Juan los puso en un horno encendido. ¿Cuál es el mejor lugar para poner los papeles?

(PINK) 16. (POINT) This boy saw a fire in a trash can and took a stick and knocked it over. (POINT) This boy got a pail of water and threw it into the trash can. (POINT) This boy ran and pulled the fire alarm. Which picture shows the bad thing to do?

16. (POINT) Este muchacho vió un fuego en un bote de basura y lo volteó con un palo. (POINT) Este muchacho le tiró agua. (POINT) Este muchacho corrió y tiró la alarma para incendios. ¿Cual hace lo que no debe hacer?

(GREEN) 17. Point to the tool Smokey Bear carries to remind him of his job.

17. ¿Qué cosa lleva Smokey para acordarse de su trabajo?

(YELLOW) 18. (POINT) This girl is playing with dolls. (POINT) This girl is starting a fire by herself. (POINT) This girl is helping her mother start a campfire. Point to the bad thing to do.

18. (POINT) Esta niña juega con sus muñecas. (POINT) Esta niña enciende solita un fuego en la chimenea. (POINT) Esta niña ayuda a su mamá encender un fuego de campamento. ¿Cuál hace lo que es malo?

(BLUE) 19. (POINT) This boy is playing with matches. (POINT) This boy is cooking hot dogs over a campfire. (POINT) This boy is fishing. Which boy makes fire his friend?

19. (POINT) Este muchacho está jugando con fósforos. (POINT) Este muchacho está cocinando hot dogs en un fuego de campamento. (POINT) Este muchacho está pescando. ¿Cuál es el muchacho que hace del fuego un amigo?

(WHITE) 20. (POINT) This girl is lighting the candles. (POINT) This girl is blowing out the candles. Which would you like to do?

20. (POINT) Esta niña está encendiendo las velas. (POINT) Esta nina esta apagando las velas a soplidos. ¿A tí qué te gustaría hacer?

ORAL TEST

FORM A

1. Can a fire be put out with papers?
¿Se puede apagar un fuego con papeles?

2. Should you leave papers and trash in your house?
¿Debes dejar papeles y basura en tu casas?

3. Are Sniff and Snuff bad?
¿Son malos Sniff y Snuff?

4. Do some trees give us food?
¿Hay algunos árboles que nos den alimento?

5. Is Smokey Bear's main job catching robbers?
¿Es el trabajo más importante del oso Smokey el coger ladrones?

6. Should you throw paper on a fire?
¿Debes echar papeles en la fogata?

7. Do firemen put out fires in the city?
¿Son bomberos los que apagan los fuegos en una ciudid?

8. Can little fires get to be big fires?
¿Pueden unos fuegos chiquitos hacerse grandes?

9. Can lightening start fires?
¿Pueden los rayos prender fuegos?

10. Can fire keep us warm?
¿Puede un fuego calentarnos?

11. Will wood burn?
Puede quemarse la madera?

12. Are tables and chairs made from trees?
¿Vienen las mesas y las sillas de los árboles?

13. If you burn your fingers will it hurt?
¿Si te quemas los dedos, te va a doler?

14. Are you afraid of big fires?
RP ¿Te da miedo los fuegos grandotes?

15. Have you ever seen a big fire?
¿Has visto un fuego grande?

16. Do you like firemen?
LP ¿Te gustan los bomberos?

17. Have you ever been burned by fire?
¿Ya te has quemado con un fuego?

18. Would you feel good to see a house burning?
LP ¿Te gustaría ver quemarse una casa?

19. Does Smokey Bear carry a shovel?
¿Lleva una pala el oso Smokey?

20. Do trees help us keep cool?
¿Pueden los árboles darnos sombra?

21. Did Smokey Bear's parents die in a fire?
¿Se murieron los papás del osito Smokey en un fuego?

22. Do you think most fires are bad?
RP ¿Crees que casi todos los fuegos son malos?

23. Do trees grow fast?
¿Pueden crecer rápidamente los árboles?

24. Is it smart to play with matches?
¿Es bueno inteligente jugar con fósforos?

25. Is watching fire burn fun for you?
LP ¿Te gusta mirar arder a un fuego?

FORM B

1. Can a fire be put out with water?
¿Puede apagarse un fuego con agua?

2. Should you leave papers and trash piled up outside your house?
¿Debes dejar papeles y basura amontonados fuera de tu casas?

3. Are Sniff and Snuff good guys?
¿Son buenos chicos Sniff y Snuff?

4. Should you stand close to a fire?
¿Debes pararte cerca de un fuego?

5. Is Smokey Bear's main job being a mailman?
¿Es el trabajo mas importante del oso Smokey el ser un cartero?

6. Can fire burn a tree?
¿Puede quemar un fuego a un arbol?

7. Do rangers help Smokey?
¿Ayudan a Smokey los guardiabosques?

8. Is it all right to play with matches?
¿Se puede jugar con fosforos?

9. Can grown-ups put out fires?
¿Pueden los grandes apagar los fuegos?

10. Can fire cook food?
¿Se puede cocer la comida con fuego?

11. Will trees grow back fast after a fire?
¿Después de un fuego en el bosque pueden crecer rápidamente los árboles?

12. Are pencils made from trees?
¿Vienen los lápices de los árboles?

13. Can playing with matches hurt you?
¿Pueden lastimarse jugando con fósforos?

14. Do you think most fires are bad?
RP ¿Crees que casi todos los fuegos son malos?

15. Have you ever seen a big fire?
¿Has visto jamás a un fuego grandote?

16. Do you like to see candles burn?
LP ¿Te gusta ver quemar una vela?

17. Have you ever started a fire?
¿Jamás has prendido un fuego?

18. Do you think it is fun to watch fires burning?
LP ¿Te gusta mirar arder un fuego?

19. Did Smokey Bear's fur get burned?
¿Se-quemó la piel del oso Smokey?

20. Does Smokey like trees?
¿Le gustan a Smokey los árboles?

21. Did Smokey ride in an airplane?
¿Viajó Smokey en un avión?

22. Are you afraid of fire?
RP ¿Le tienes miedo al fuego?

23. Do trees grow very slowly?
¿Crecen despacito los árboles?

24. Is it bad to play with matches
¿Es malo jugar con fósforos?

25. Would you like to see a forest fire?
¿Te gustaría ver a un fuego en el bosque?

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Folkman, William S., and Jean Taylor.

1972. **Fire prevention in California's Riverside County Headstart Project. . .an evaluation.** Berkeley, Calif., Pacific SW. Forest & Range Exp. Stn. 29 p. (USDA Forest Service Res. Paper PSW-79)

An especially designed series of fire prevention lessons were taught to preschool children in the Headstart Project in Riverside County, Calif. Their effectiveness was evaluated by observing classroom reaction and by testing the children at the end of the year. The results suggest that this type of educational approach is feasible.

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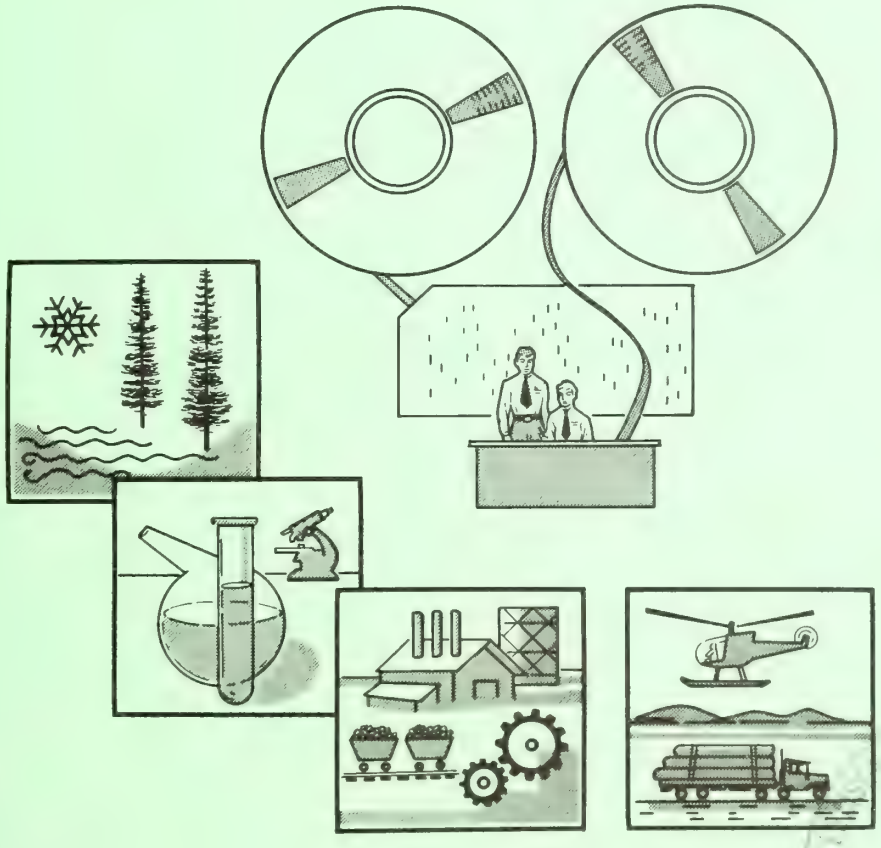
# AN ANALYTICAL PROCEDURE TO ASSIST DECISION-MAKING

## in a government research organization

H. Dean Claxton  Giuseppe Rensi



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# FOREWORD

Evaluating proposals for inclusion in a research program is an important, continuing, and difficult decision process for the research administrator. He usually decides on the basis of intuition and knowledge. Typically, only a small amount of data and analysis is available to him before proposals are selected and molded into a research program.

Recognizing the potential for improving this process, the consistency and perhaps the quality of the decisions, the Forest Service started both theoretical and empirical studies in 1967. Theoretical work was done at the Pacific Southwest Forest and Range Experiment Station in cooperation with the University of California, Berkeley. The U.S. Forest Products Laboratory at Madison, Wisconsin, cooperated by providing data for both theoretical and practical work.

The procedures reported in this paper were developed by the Station in cooperation with the University of California, Berkeley. This report is a companion to *A Data Collection and Processing Procedure for Evaluating a Research Program*, published by the Station as USDA Forest Service Research Paper PSW-81.


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This paper considers the problem of planning research in two sections. First, a conceptual framework is proposed in which objectives, activities, and constraints of a government research organization are considered in a functional systematic manner. Second, a procedure is introduced that can assist decision-making in such an organization. Methodology, theoretical constructs, and empirical propositions from economics, operations research, and mathematical programing are used in developing the proposed procedure, and in substantiating its results.

In the conceptual framework of section one, research administration is viewed as a set of operations leading to the allocation of available resources among competing research activities. These operations consist primarily of acquiring, processing, and utilizing information. The two major categories of information involved are data on alternative research possibilities, and data on preferences among alternatives. Acquisition and processing of data in both categories are considered. Several major problems areas in public research planning, such as multiple objectives, uncertainty of research outcomes, and time preferences for future benefits are discussed within this framework.

The second section proposes a specific procedure to analyze alternatives and to assist a research planner in reaching allocation decisions. In this section, we also utilize the conceptual framework developed in section one to specify information requirements and to suggest methods of bringing the information together for analysis.

# OBJECTIVES, ACTIVITIES, AND CONSTRAINTS

A government research organization can be usefully described in terms of objectives, activities, constraints, and the interrelationships between them. On the basis of Tinbergen's (1966) classification of policy variables, the objectives of a government organization can be defined as target variables. The research activities of the organization may be considered as instrument variables or strategies to be used in pursuing targets. Any remaining variables represent elements over which the administrator exercises a lesser degree of control. These uncontrolled variables should be considered fixed constraints. Understanding and identifying objectives, activities, and constraints are essential for planning operations. This section describes a framework to assist in identifying and understanding these variables for a government research organization.

## *Objectives and Effectiveness*

Objectives for a government research organization are usully established through an interactive process of communication between various levels of the executive hierarchy. Broad statements of purpose are generally issued at the top. These provide guidelines for establishing more precise directives at lower levels. Eventually a detailed program of activities is generated by the research organization. Thus a process of identification, analysis, and specification takes place in which a list of targets or operational objectives is distilled from broadly spelled out recommendations. Whether or not this process of communication and interaction takes place in a highly structured manner, through institutionalized procedures and channels, or in a more informal fashion, the end result is a set of operational objectives which can be used as planning parameters. In operations planning, objectives are appropriately defined only when it is possible, at any point in time, to unambiguously determine the degree to which they have been accomplished. Measurable objectives have this property.

If an organization had a single objective, then alternative programs of activity could be ranked and evaluated in terms of their effectiveness in the achievement of this objective. Thus a standard of effectiveness would be readily available.

When an organization has several different objectives, such notion of effectiveness is generally not sufficient to establish a ranking of alternative policies. A performance matrix for three alternative plans in terms of three measurable objectives will illustrate this point:

| | *Objectives* | | |
|---|---|---|---|
| | *1* | *2* | *3* |
| Programs: | | | |
| A | 1,000 | 20,000 | 500 |
| B | 500 | 20,000 | 1,000 |
| C | 500 | 20,000 | 500 |

Undoubtedly program C is least desirable, but it is not possible, on the basis of the information displayed, to decide between programs A and B. In fact, A performs better in terms of objective 1, and B performs better in terms of objective 3. This difficulty can be resolved only by introducing an equivalence ratio between objectives 1 and 3. The equivalence ratio of objective 3 in terms of objective 1 expresses the number of units of objective 3 which are equivalent to one unit of objective 1. In the example, program B is determined to be superior, inferior or indifferent to program A by the equivalence ratio of objective 3 in terms of objective 1. If the ratio is greater than one, program A is superior to program B.

The idea can be stated more generally. Given K objectives, K-1 equivalence ratios are needed to define a measure of effectiveness which can be used in ranking alternative action programs. Given a list of operational objectives for a government organization the specification of a corresponding list of equivalence weights represents a precise definition of the decision-maker's hierarchy of priorities.

On a higher level of generality the hierarchy of priorities among objectives can be considered as varying with the degree of achievement of the different objectives. For example, the desirability of objective 1 with respect to objective 2 may be assumed to vary according to the extent to which 1 and 2 are being achieved. This discussion of comparative desirability introduces the notion of a preference function familiar to readers of economic theory. The problem of measuring the effectiveness of multi-objective programs is a special case of the broader problem of aggregating noncommensurable items. An analytical solution of the problem entails the specification of a mapping that transforms multidimensional values into a one-dimensional measure. This mapping can be chosen to be an average or mean function. Thus an optimum average function would represent an ideal solution.

In multiple-objective planning, two sets of information items are necessary: a set of individual objective achievement measures, as arguments of the average; and a set of preference weights, as parameters of the average. In practice, it may be difficult to establish a sound data base for these items. Nevertheless, it is important to clearly define the types of information sought.

Information about measures of objective achievement can be characterized as "technical" or "factual." It consists in estimates of the expected effects of a specific plan of action as they contribute to individual objectives. As an example, consider the effects of a specified research activity on the gross national product, measured in dollars. This piece of information can be consolidated in the form of a numerical prediction representing a consensus among competent technical experts.

Information about preference weights can be viewed as pertaining to value judgments. It presupposes a specification of priorities among social objectives. Questions such as "What is the dollar value of one human life?", to choose a typical example, may have to be raised and answered in this context. Such information is to be established in the form of determinations and judgments reflecting some consensus. Only, here the experts are not so much the scientists or the technicians, but those empowered with the responsibility of interpreting the priorities of public interest.

The information outlined above may not possess the character of the "hard" data that one may find desirable for analysis. On the other hand, it is relevant data. Also, there is no *a priori* reason why the reliability of these data should not increase in proportion to the effort exercised in obtaining them. Securing a consensus through documentation and assembly of supportive materials should increase the reliability of data. The definition of effectiveness in terms of multiple objectives is determined by the type of information available. Examples of utilizing different types of information in formulating a multiple objective problem can be given for specified objective measurements, market-derived measures, and a mixture of the two.

Consider a government research organization with K objectives and P alternative plans of action, i.e., research programs. Assume that each objective is measurable in some specified units. Let $O_{kp}$ represent the expected achievement of objective k using plan p. Let $W_k$ be the priority weight of the kth objective on a specified ranking scale. This means, for instance, that one unit of objective 1 is worth $W_1/W_2$ units of objective 2. Assuming an arithmetic average function, an effectiveness measure for plan p can be expressed as

$$E_p = W_1 O_{1p} + W_2 O_{2p} + \ldots + W_K O_{Kp} \qquad (1)$$

This formulation can be displayed in "tableau" form *(fig. 1)*. Obviously it is not possible to calculate the efficiency of a plan according to formula (1) unless the $W_k$'s are specified. This requirement corresponds to the common-sense notion that it is not possible to plan at all unless the hierarchy of priorities among objectives is known or agreed upon.

| Alternative Plan | Measure of accomplishment in objective | | | | Plan effectiveness |
|---|---|---|---|---|---|
| | 1 | 2 | . . . | K | |
| 1 | $O_{11}$ | $O_{21}$ | . . . | $O_{K1}$ | $E_1 = \sum_k^K W_k O_{k1}$ |
| 2 | $O_{12}$ | $O_{22}$ | . . . | $O_{K2}$ | $E_2 = \sum_k^K W_k O_{k2}$ |
| 3 | $O_{13}$ | $O_{23}$ | . . . | $O_{K3}$ | $E_3 = \sum_k^K W_k O_{k3}$ |
| . | . | . | . . . | . | . |
| . | . | . | . . . | . | . |
| . | . | . | . . . | . | . |
| P | $O_{1P}$ | $O_{2P}$ | . . . | $O_{KP}$ | $E_P = \sum_k^K W_k O_{kP}$ |
| Priority weights | $W_1$ | $W_2$ | . . . | $W_K$ | |

**Figure 1**—Multiple-objective effectiveness index as calculated on the basis of ideal measures of (a) achievement of objectives, (b) relative priority of objectives.

In other cases, economic information can be used to construct measures of effectiveness of public programs. These are cases in which attainment of social objectives can be readily translated into a notion of economic value. In many instances, government activities result in increased production of goods and services or in savings in the use of productive resources. When planning involves such activities, efficiency for a plan p can be defined as

$$E_p = Q_{1p} V_1 + Q_{2p} V_2 + \ldots + Q_{Np} V_N \qquad (2)$$

in which $Q_{ip}$ are measures of production increases or resource savings and $V_i$ are the corresponding prices of commodities or resources. This formulation can be displayed in "tableau" form *(fig. 2)*.

Formula (2) is analogous to formula (1), except that priority weights [W] have been replaced by market prices [V]. In other words, the prices generated by the market mechanism serve as reliable indexes of public preferences. On the other hand, there are situations in which public benefit may not be reflected in market prices nor even expressible in terms of economic values. In some cases, social objectives may not be equated with increased efficiency in production of marketable commodities. In other instances, public goals involve the production of services whose market pricing is either nonexisting or inadequate from a social viewpoint. Using economic incentives as criteria to decide upon the public desirability of certain government activities may also have the disadvantage of validating any inadequacies inherent in the social performance of the private sector. If these pitfalls are recognized, judicious use of economic data and economic justifications can provide assistance to government decision-making bodies—especially when a precise definition of political priorities is absent *(fig. 3)*.

As a compromise solution a computation of efficiency based on formula (3) can be proposed:

$$E_p = W_p (Q_{1p} V_1 + Q_{2p} V_2 + \ldots + Q_{Np} V_N) \qquad (3)$$

According to formula (3), the economic assessment of plan p—computed as in formula (2)—is adjusted by a factor, $W_p$, to account for possible divergences between economic and social performance of the plan. $W_p$ is estimated on the basis of the proportion of net social benefits to net economic benefits expected from plan p. More precisely, let $E_p$ be the over-all benefit of plan p. Assume that

$$E_p = E_p^* + EE_p$$

i.e., the total benefit can be broken down into an economic portion $E_p^*$ and an extra-economic component $EE_p$. Then $W_p$ is defined by the formula

$$W_p = E_p/E_p^* = 1 + EE_p/E_p^*$$

In formulating plans, objectives can be specified as fixed targets or as open-ended performance dimen-

| Alternative plan | Measure of product increased or resource saved in industry | | | | Plan effectiveness |
|---|---|---|---|---|---|
| | 1 | 2 | · · · | N | |
| 1 | $Q_{11}$ | $Q_{21}$ | · · · | $Q_{N1}$ | $E_1 = \sum_i^N Q_{i1} V_i$ |
| 2 | $Q_{12}$ | $Q_{22}$ | · · · | $Q_{N2}$ | $E_2 = \sum_i^N Q_{i2} V_i$ |
| 3 | $Q_{13}$ | $Q_{23}$ | · · · | $Q_{N3}$ | $E_3 = \sum_i^N Q_{i3} V_i$ |
| . | . | . | | . | . |
| . | . | . | | . | . |
| . | . | . | | . | . |
| P | $Q_{1P}$ | $Q_{2P}$ | · · · | $Q_{NP}$ | $E_P = \sum_i^N Q_{iP} V_i$ |
| Economic prices | $V_1$ | $V_2$ | · · · | $V_N$ | |

**Figure 2**—Multiple-objective effectiveness index as calculated on the basis of market derived measures.

| Alternative plan | Product increased or resource saved in industry | | | | EE factor[1] | Plan effectiveness |
|---|---|---|---|---|---|---|
| | 1 | 2 | · · · | N | | |
| 1 | $Q_{11}$ | $Q_{21}$ | · · · | $Q_{N1}$ | $W_1$ | $E_1 = W_1 \sum_i^N Q_{i1} V_i$ |
| 2 | $Q_{12}$ | $Q_{22}$ | · · · | $Q_{N2}$ | $W_2$ | $E_2 = W_2 \sum_i^N Q_{i2} V_i$ |
| 3 | $Q_{13}$ | $Q_{23}$ | · · · | $Q_{N3}$ | $W_3$ | $E_3 = W_3 \sum_i^N Q_{i3} V_i$ |
| . | . | . | | . | . | . . |
| . | . | . | | . | . | . . |
| . | . | . | | . | . | . . |
| P | $Q_{1P}$ | $Q_{2P}$ | · · · | $Q_{NP}$ | $W_P$ | $E_P = W_P \sum_i^N Q_{iP} V_i$ |
| Economic prices | $V_1$ | $V_2$ | · · · | $V_N$ | | |

[1] "Extra-economic" adjustment factor.

**Figure 3**—Multiple-objective effectiveness as calculated on the basis of market derived measures as well as other parameters of social utility.

sions. For example, a goal of economic growth can be specified as "increase GNP by 5 percent." This increase represents a fixed target. The corresponding open-target specification would be "maximize GNP." Whether an objective is specified as a fixed or an open target makes a difference when competing plans are compared in terms of that objective. With respect to a fixed target, competing plans can be classified into two types: (a ) those that achieve the specified target or better; and (b) those that fall short of the target.

All plans in either category are equivalent to all other plans in that category in terms of effectiveness, in other words, fixed target objectives can be stated as feasibility constraints.

Defining performance in terms of a plurality of objectives can be done in another way. One major objective can be specified as an open-ended effectiveness dimension. All other objectives can be stated as fixed effectiveness levels. This method reduces the problem of ranking alternatives under a multiplicity of objectives to the simpler case of a single objective. Alternative plans that satisfy minimum effectiveness requirements in terms of the fixed target objectives can be conveniently ranked according to the primary, open-ended objective.

## Activities and Programs

A *program* can be defined as a list of activities to be carried out. In the planning stage a number of alternative programs can be considered. Effective planning consists of selecting the program having the best performance. In general it is advantageous to consider the largest possible number of alternative programs. Conceptually then, programs can be generated by specifying the complete set of activities which could conceivably be carried out, then defining alternative feasible programs as subsets of the complete set of activities. To be feasible a program must be consistent with constraints that limit the organization's freedom of action. For instance, a program may not be feasible because it requires an outlay in excess of the available budget. In other cases, a program may demand skilled services in excess of those which the organization can procure. In addition, organizational regulations and considerations reflecting requirements of internal cohesion may render some programs unacceptable.

An *activity* is usefully defined as an output-identified operational unit. This definition emphasizes the requirement that the output expected from a research activity determines its separate and distinct identity. Operational units so defined may or not correspond to administrative or budget accounting units. An administrative unit may embrace several "activities" or, conversely, one activity may involve more than one administrative unit. For planning purposes administrative units and planning units need not be identical.

Identifying the output of a research activity as a specific and clearly defined target is a necessary prerequisite for *a priori* evaluation and retrospective assessment of the activity itself. The expected output of a research activity may be collections of data, classifications of data, formulations of hypotheses, testing of hypotheses, or advancements of theories. In addition, research outputs might consist of applications of scientific knowledge which creates technological innovations in the form of new products or new processes. To assign a measure of socio-economic value to the expected output from a research activity, two sets of information are required: (a) the anticipated socio-economic effects of the expected research product; and (b) the time schedule in which these effects are expected to materialize.

In the process of identifying gains from research it may be convenient to separate economic and extra-economic gains. "Economic" gains are contributions to public good which can be readily assessed in terms of dollar measures. "Extra-economic" gains, or losses, represent that portion of foreseeable socio-economic effects which have not been adequately considered in the economic analysis of a research activity. Important aspects sometimes overlooked in the economic accounting of public value are: (a) macro-economic effects, such as repercussions on income distribution, rates of employment, etc.; and (b) externalities. Externalities occur whenever social gains or sacrifices are forced upon the public at large as byproducts of economic decisions on the part of private individuals or organizations. For instance, the social cost of air pollution does not appear as a production-cost component of auto manufacturers. Sometimes a government institution engages in a research activity which is simultaneously carried out by some other party. The public cost implicit in this duplication of effort as well as all other instances of "extra-economic" benefits or costs should be accounted for in the assessment of the socio-economic impacts of government funded research. This accounting can be done by (a) constructing a dollar measure of value of an activity on the basis of its predicted economic results; and (b) adjusting such measure by means of a "social priority multiplier" type of measure. The social priority multiplier should reflect the over-all social utility of a research activity relative to its

strictly economic merits. Using this procedure a dollar measure of socio-economic value of a research activity can be obtained. Such a measure will be referred to as the activity's *benefit.*

A major difficulty encountered in the determination of "benefit" involves intertemporal value comparisons. Benefits from research accrue in time streams. How are benefits generated in earlier years to be compared with gains in later years? If benefits are expressed in dollar equivalent units, the problem can be stated in terms of discount rates, namely, what is a suitable rate of discount to compare dollar values produced at different points in time? This is a subcase of the more general problem of a multidimensional achievement function discussed in the subsection on objectives. In fact, dollar benefit in year t can be viewed as a different performance dimension with respect to dollar benefit in year t + 1. The choice of a discount rate in calculating the present value of a stream of future benefits is crucially important. Grossly speaking, a lower rate of interest[1] tends to make the present value of longer-term projects relatively larger compared to shorter-term projects; a higher rate would tend to make it relatively smaller. The issue of the rate of discount to be used in the analysis of government programs—the social rate of discount— is widely debated in the economic literature. Two conflicting sets of considerations affect the choice of an appropriate rate.

One set of considerations emphasizes the problem of optimum resource allocation between private and public sectors of the economy. No matter how the government finances its enterprises, whether through taxes, borrowing, or inflation, in real terms it takes away scarce input resources from the private sector. To allocate resources efficiently, public agencies should evaluate them by using the same rate of return as would be used in the private sector. This rate would include not only the average rate of return to funds invested by individuals in the business sector, but also that fraction of those earnings from investments that are taxed. If this line of reasoning were followed the government would, on the average, use higher rates of interest than those presently used in computing present values of public projects (Baumol 1968).

The other set of considerations concerns the question of society's preferences. Individuals are more prone to forego present benefits in favor of future ones in public projects than in private projects. This may be so because they invest in a public enterprise knowing that others must also contribute through taxation. In other words, individuals will undertake more investment collectively than each person finds desirable to undertake privately because the extra sacrifice "becomes insignificant in comparison with the psychic gains and losses from others' investment" (Marglin 1963). This set of considerations may be used to rationalize the application of lower rates of interest in discounting dollar measures of future benefits in government projects.

These two polar positions reflect conflicting beliefs and attitudes concerning the comparative effectiveness of the machinery available in either the public or private sector for interpreting and implementing individuals' preferences concerning investments for future generations. In practice, a market-generated rate of interest can be relied upon as a guide in establishing discount rates suitable for government-financed programs.[2]

The length and shape of the time stream in which results will flow from a research activity depends in general on the level and intensity of the resource investment. Thus the benefit of a research activity, as measured by dollar present value, varies according to the magnitude of resources invested. Consequently, the dollar benefit measure attached to a research activity implies and presupposes a specific level of resource requirements.

Another major problem encountered in the quantitative specification of a research activity is the uncertainty surrounding the steps required for its successful completion and implementation. The process through which a research activity generates desired results can be viewed as a sequence of steps. Each step involves a particular obstacle to be breached. A breakthrough in each step is necessary for the research activity to produce its planned end results. If perfect knowledge existed about the steps required and the actions needed to overcome these obstacles, a research activity would not differ from an industrial production operation.[3] For typical research activities the necessary steps and associated operational requirements are not known *a priori.* As research progresses, new information becomes avail-

[1]The relationship between rate of interest i and rate of discount d is: $d = (1 + i)^{-1}$.

[2]See *Survey of use by Federal agencies of the discounting technique in evaluating future programs.* Report to the Joint Economic Committee of the Congress of the United States by the Comptroller General of the United States. Jan. 29, 1968.

[3]Technical uncertainty exists also in production activities, e.g., agricultural production, but to a lesser degree.

le concerning the steps required and the difficulties volved. It is then problematic, given a specified end sult, to determine exactly the amount and timing of ork and resource use needed to obtain it. Conrsely, given a specified amount of resources avail-le for a research enterprise it is difficult to termine exactly when a certain research target will achieved.

The exact relationship between level and timing of source use and level and timing of research output mains uncertain. As a consequence any explicit ecification of benefit and resource requirements for research activity is subject to a degree of uncerinty. Such uncertainty can be quantitatively exressed in a "chances of success" measure. This arameter introduces a probabilistic element in the uantitative assessment of a research enterprise. It xpresses the degree of confidence that a specified me stream of resource use will yield a planned search result. The "chances of success" measure can e interpreted as a certainty equivalence factor for he benefit of a research activity. This factor converts ncertain benefits into the corresponding uncerainty-free values. Resource intensity, time of comletion, and chances of success are three closely nterrelated elements. Consequently several "verions" of a research activity can be conceived of, each ne characterized by a particular triplet of values for he three parameters. In some cases it may be onvenient to express the interdependence between esource intensity, time of completion and chances of uccess by means of a functional relation.

## Constraints

A research program is feasible if it is consistent with the constraints affecting the organization. The various types of constraints include limited resources, minimum performance, internal allocation, and interdependence constraints.

### Limited Resource Constraints

A government research organization is not endowed with unlimited amounts of resources with which to carry out its activities. The limitations on the availability of resources may affect (a) the money budgets available in each year of the planning period; (b) the availability of physical facilities, such as buildings, laboratories, or special equipment items; and (c) the availability of specially skilled personnel. To pass the feasibility test with respect to these constraints a research program must not require resources in excess of the amounts available in each category.

### Minimum Performance Constraints

The benefit measure represents an over-all effectiveness measure based on all of the organization's objectives, but it may be desirable for the organization to specify separately minimum levels of achievement for certain specific objectives. Such minimum levels may be specified in terms of input units as well as expected output units. One such specific objective may be, for example, basic research[4] or pollution control research.

### Internal Allocation Constraints

Some government research organizations, especially larger ones, may have an administrative structure involving several subunits with considerable degree of autonomy. A research program for the whole organization implies a certain allocation of the budget monies and other resources among the administrative subdivisions. If such allocations were to excessively penalize one or more of the subunits, the internal stresses generated could threaten the cohesion of the organization. A research program with these allocational implications may be ruled out as unfeasible. Constraints of this type could be stated as minimum budget requirements for each subdivision either as absolute amounts or as fractional shares of the total budget.

### Interdependence Constraints

A research activity may be defined in such a way that it cannot be carried out unless one or more complementary activities are executed as well. This is an example of positive dependence. On the other hand, two or more activities may be mutually exclusive, i.e., only one out of a specified set of activities may be considered. This is a case of negative dependence. A typical case of negative dependence occurs when several "versions" of a research activity are proposed, each version characterized by a different level of resource use. If only one among these versions is allowed to enter the organization's research program a negative dependence constraint is present. Such constraint requires that the various "versions" of the same activity be mutually exclusive.

[4] In terms of the discussion on uncertainty in the section on Activities and Programs "basic research" can be characterized as highly uncertain research, i.e., research in which there are many unknown steps between inception and achievement of foreseen end results.

### *Interrelationships in Optimization Models*

Objectives, activities, and constraints constitute the building blocks of optimization models. An optimization model may provide the basic framework for efficient organization planning. It can facilitate thorough understanding and rational utilization of information pertaining to a decision problem. A suitable optimization model serves to: (a) simulate the situation at hand; (b) postulate the conditions of rational behavior in the decision process analyzed; and (c) efficiently communicate the relevant data and knowledge of the problem. Simulation consists of selecting certain elements and relationships as representative of the situation under consideration, then formulating hypotheses regarding the nature of these relationships. Postulating conditions of rational behavior is equivalent to defining rules and criteria that identify the best or optimum decision. Efficient communication amounts to defining and using terms with a precise and constant meaning.

The mathematical formulation of a decision scheme consists of using mathematical symbols and conventions to specify the variables representing objectives, activities, and constraints, and the relations among these variables. Such formulations of decision problems have the advantage of allowing the conciseness and internal consistency inherent in the logical method to be exploited. They also afford the possibility of using mathematical optimization techniques and corresponding computational algorithms to determine best decisions.

In most concrete situations the variables relevant to the decision problem at hand are numerous and their interrelationships highly complex. A consequence of such complexity is the latitude left to the analyst in designing an appropriate scheme. In building a model, he invariably selects a particular set of facts as important and excludes others as immaterial. In an overly simple model, relevant variables and relations may be either omitted or too grossly approximated. Such a model would be of limited usefulness in the analysis of complex decision problems. As additional relevant variables are introduced and relations specified in greater detail, a model becomes more effective in providing meaningful answers. From a technical viewpoint, a variety of alternative procedures can be envisaged. Nonlinear as well as linear relations may be postulated, stochastic as well as nonstochastic variables may be specified, and dynamic instead of static assumptions may be introduced.

On the other hand, increasing the degree of complexity of a model involves some disadvantages. Not only does it become more difficult to find or develop appropriate mathematical techniques and computational algorithms, but, also, the information requirements for numerical implementation become more drastic. In some cases information may not be available in the amount and detail specified by the model; in others, the procurement of the information required may involve an expenditure in excess of the value of the answers that the model could provide. Thus a correct perception of the advantages and disadvantages associated with various degrees of complexity should assist the researcher in the selection of the model which is best suited for the analysis of a specific decision problem.

A decision model of research management, therefore, involves these phases: (a) definition of effectiveness criteria, (b) comparison of feasible research programs, and (c) selection of best research program. Examples of mathematical formulations of research planning aspects are briefly outlined in *Appendix A.*

## PROCEDURE FOR PROGRAM FORMULATION AND EVALUATION

The procedure for formulating and evaluating a research program consists of two phases: (a) acquiring and validating the information, and (b) using the information in decision making. Phase 1 involves collection of data, updating and cross-checking of information while phase 2 deals with the conversion of data into a form usable for decision-making purposes. Portions of these operations can be designed to take full advantage of automated data processing capabilities (Rensi and Claxton 1972). Underlying the procedure there are assumptions as to what are the relevant data for the problem of research administration. Identification and classification of relevant data are based upon the model of a government research institution sketched in the previous section. Data can be organized under two main headings—data on individual research activities, and data pertaining to the organization as a whole.

Data on individual research activities can be assified as follows:

1. Identification
   a Identification code
   b Researcher in charge
   c Research target
2. Expected resource use
   a Time of completion
   b Budget expenditures
   c Use of other limited resources
   d Chances of completion
3. Expected utility contributions
   a Time series of economic benefits
   b Contribution to other performance criteria
   b Extra-economic adjustment factor
   d Chances of successful implementation
4. Documentation
   a Sources and references
   b Methods and assumptions

em lc, "Research target," is specified in such a way at it is possible at any time to unambiguously etermine whether the research activity has been ccessfully completed. A research target can fall into ny of four classes:

1. Collection, survey, or inventory of data
2. Classification of data
3. Formulation and testing of hypotheses
4. Development of technological applications

is important to distinguish between the "target" of research activity and the "applications" of a mpleted research activity. The research target refers the "research phase" of the activity. The research hase may be followed by an "implementation hase," i.e., the conversion of research results into cio-economically useful applications. In some cases e "implementation phase" takes place outside the search unit or the research organization responsible r the "research phase."

In item 2c, "Other limited resources," are defined s resources other than budget monies which are vailable in limited short-run supply to the research rganization. Item 2d, "Chances of successful com-letion," expresses the degree of confidence that the search activity will be successfully completed under me and resource uses as specified in sequences 2a hrough 2c.

Sequences 3a through 3d refer to one potential pplication of the research activity. Any additional pplication is documented likewise. "Economic benefits," as in item 3a occur when technical innovations are introduced into the industrial system to increase efficiency in production. They can be assigned either to new (improved) products and services or to new (improved) processes and methods. "Contribution to other performance criteria," item 3b refers to criteria other than economic benefits as such. Examples of criteria other than national wealth would be air pollution abatement, and reduction of urban congestion. Item 3c, "extra-economic adjustment factor," estimates the relative discrepancy between total public good and dollar value as determined through economic accounting. "Chances of successful implementation," is a measure of the degree of confidence that the application reported will generate the socio-economic utility described in 3a through 3c.

Data on the research organization as a whole describe the organization's restrictions and can be grouped as follows:

1. Projected budget limits.
2. Projected other limited resources limits.
3. Other performance criteria targets.
4. Internal allocation restrictions.
5. Interdependence restrictions.

This two part data classification scheme and its suggested subclasses is comprehensive in the sense that it covers all the elements that are relevant to decision making. It is also a flexible scheme since the data organized in such fashion can be used in the context of a variety of optimization techniques.

## *Acquisition and Validation of Information*

### Data Collection

Data pertaining to an individual research activity, such as that classified above, is produced in the process of preparing a "research proposal." A "research proposal" is the document accompanying the official request for funding of a research activity. Before being embodied into a formal proposal a given idea of a research activity is "kicked around" informally and, if necessary, modified until it appears to be by and large consistent with the perceived mission, scientific competence, and resource endowment of the research organization. The operations described above refer to a "new" research activity, i.e., a research activity which is being proposed for the first time. Conversely, a research activity is either "active" if it is currently going on, or "inactive" if it

is on the waiting list. Data on the research organization as a whole are collected on a continuous basis as new information on organizational restrictions becomes available.

### Updating Information

The information filed in the "dossier" of each research activity, as well as of the organization as a whole, is routinely updated on a continuous basis. Updating involves filling in information previously unavailable, and replacing obsolete data. Updating applies to new, active or inactive activities. The basic classification scheme remains intact; only the numerical estimates under each item are modified in the updating process.

Suppose, for example, that a breakthrough has taken place which will accelerate progress toward the accomplishment of activity X's research target. Then items 2a through 2d in activity X's file require updating. Another example: a discovery made in a competing field will render obsolescent the innovations attributed to activity Y. It is then necessary to reestimate items 3a through 3d in the "dossier" of activity Y.

Similarly, for the file of the organization as a whole, if new data become available on monetary budgets, resource availability, etc., the appropriate entries in the file must be revised.

The filing and updating scheme described is compatible with the requirements of automatic data processing. The speed and versatility of modern devices make it possible to handle a great amount of data and to reorganize the information in many different formats to suit particular needs or preferences. Thus a variety of updated reports could be produced to reflect the current status of a government research organization.

### Cross-Checking Information

Part of the information filed consists of anticipation of future events. In some instances, value judgments and assessments of public priorities are explicitly or implicitly involved. Cross-check is a procedure by which anticipations and judgments are cleared, as much as possible, of inaccuracy and bias. Inaccuracy and bias may depend on vested interest as well as insufficient documentation. A thorough revision of the filed information is conducted, and estimates and measures are adjusted until they can be considered to represent the consensus of opinion or the best agreement of impartial, competent people. Generally, it is desirable to have the judgment of more than one expert, even if their opinions usually differ.

There are several ways to try for a consensus. One way is to gather the experts in one place, let them discuss the validity of the estimates, and require them to negotiate a joint answer. They could also be put to work separately, leaving to others the task of consolidating their findings into a joint assessment. Alternatively, experts could be invited to participate in group exercises ranging from structured discussions to more sophisticated techniques such as "operational games," "scenario writing," and "simulated debate" (Delphi method). Operational games involve role playing by individuals representing decision-makers in a simulated real world situation. Scenario writing is an exercise requiring experts to exhibit a reasonable chain of events through which a future state might be evolved from the given one. A collection of scenarios might provide insights into the liklihood of the occurrence of anticipated outcomes. In the Delphi method, direct panel debate is replaced as the means for the interchange of information and judgment by a carefully designed sequence of questionnaires. At each successive round, the participants are provided with more refined information representing feedback from previous rounds. The process continues until either a consensus is established or a dissenting view is fully documented.

The consensus-securing procedure to be adopted in any specific case depends on the type of organization involved. In general, the following considerations can be made. First, cross-checking consists of a thorough and complete review of an organization's list of research proposals. This process involves, at least for organizations over a certain size, a large amount of energy and effort. Consequently, cross-checking should be done once a year assuming yearly budget periods. The time of the year might be chosen to coincide with the period in which the current program is to be evaluated in terms of the past year's performance and the program for the new budget year is to be prepared. Secondly, different information items have to be established by different types of experts. For instance, item sequence 2a through 2d requires the consensus of competent scientific people in the research area considered. Estimates 3a, 3b, and 3d should be agreed upon by production and marketing specialists, who know the industrial sector affected by the application. Information under 3c should represent the agreement of a variety of interest groups, such as government, labor unions, and consumer groups. Thirdly, the process of cross-checking does not lend itself readily to automatic

manipulation. Human judgment plays the major role in this process, and rightly so, given the nature of the task performed. Although the remaining steps of the procedure could be substantially automated, cross-checking would still have to be completed by, and under the control of, administrative personnel.

A possible use of the computer in cross-checking is to execute error-testing routines that can be applied systematically to spot possible areas of error. This warning method can be used to direct the attention of the auditors to estimates that may be suspect. For instance, if there is an exorbitant discrepancy between a project's cost requirements and its expected benefits, these estimates should be marked for further investigation and documentation.

## *Use of Information in Decision-Making*

Once information has been collected and validated it can then be used for decision making. The techniques of optimization and analysis outlined here will enable the decision-maker to make full use of the information that is available. The conceptual framework established in previous sections enable him to consider optimization techniques that will select programs having known and desirable properties. Harnessing high speed computing capabilities to facilitate both data handling and optimization further provides a variety of analytical options (Rensi and Claxton 1972). This capability gives managers great power to explore, test, and validate their assumptions and opportunities, and to project and substantiate their organization's potential for growth and developement.

An optimization technique discussed in *Appendix B* has proved to be a powerful tool for providing solutions with desirable properties. The integer programing technique suggested will also easily accommodate the complex formulation required to include important aspects of this decision-problem. The technique has proved to be sufficiently powerful in this respect that the restraining factor seems to be data availability rather than expression and manipulation of complex relationships.

### The "Optimum" Program

A key result derivable from the information available is identifying the largest benefit attainable. Once the largest attainable benefit is identified, it can be used as the 100 percent mark for an efficiency scale against which any alternative program can be evaluated. Associated with the largest benefit is a program that produces the largest benefit, i.e., an optimum program. No other feasible program can be found with a larger benefit. An optimum program is also a feasible program, i.e., a program within the range of the organization's options as determined by the constraints. No alternative choice other than an optimum program can be justified unless the validity of the underlying model or the data are questioned; in other words, the finding of an optimum or best program is contingent upon the model of the organization selected and the validity data used. Different models of a research organization represent different statements and imply different measurements of objectives, activities, constraints and their interrelationships as illustrated in *Appendix A*. Consequently, each model involves its specific definition of optimum. Also, as noted above, even when the choice of the model is unobjectionable, the quality of the data used to implement the model may be such as to invalidate the identified "best" option.

An optimization scheme may be structured in such a way that the optimum solution generated consists of a set of binary decisions concerning each potential research activity. A zero-one integer programing formulation of this nature is described in *Appendix B*. A "yes" decision on a research activity may be interpreted as a recommendation that the research project be carried out. The opposite holds for a "no" decision. In this context a research activity is evaluated not only as a separate project on the basis of its own specific merits, but also in its relation to the over-all research objectives and resources of the organization. A research activity may consist of a new proposal as well as of an ongoing project. Activities representing ongoing research are considered on the same basis as activities involving new research proposals insofar as only future resource requirements and expected contributions are taken into account. Past costs and benefits, "per se," are left out of the computations affecting future decisions. On the other hand, the "goodwill" element that may be associated with ongoing research pursuits is given adequate recognition in the data collection format proposed above to the extent that it is reflected in the estimates of "time of completion" and "chances of completion." The benefit of the optimum program represents an adequate parameter of the total worth of the planned activities of a research organization at a given time. Accordingly, it can be used to construct an index of the organization's present worth in terms of its potential for future results. Intertemporal comparisons of index magnitudes may offer an

indication of the organization's position in its growth dynamic. Such indications may be used as an input for long-run policy decisions.

### Analysis

A technique called "sensitivity analysis" is used to detect the sensitivity of the optimal solution to variations in the parameters of the problem. The more the optimal solution varies in response to a modification of a parameter, the more sensitive the solution is to that parameter.

This form of analysis is a powerful instrument for identifying factors that inhibit optimum effectiveness of the organization. Not only can major inhibiting factors be identified, but also the mode and the extent of their impact can be described and measured. Two measures seem to be of interest in the analysis. One, the most obvious, is the comparison of the total benefit derived from different values of the parameter under consideration. The other is the change in activity mix that results from changing parameter values.

The following suggestions do not presume to be exhaustive, but are presented to illustrate the potential of this method of analysis.

### Constraint Removal or Relaxation

Adding and removing whole constraints may be within the power of the organization. Similarly the level of any restriction may be modified to a more or less desirable level. The over-all effects can be measured in terms of both effectiveness and the activity mix. The truth of the statement "we feel our organization would improve its performance if our budget were expanded" can be confirmed or rejected in a rigorous way by using sensitivity analysis. Possible limiting factors such as skilled personnel or equipment endowments may turn out to be real restrictions or merely specters. Restrictions with the strongest impacts can be identified. Internal restrictions, such as "each research division must be allocated an equal share of the total funds," or special objective restrictions such as "basic research projects must be allotted no less than one third of the total budget," may also have negative repercussions on the performance of the organization. In this case their modification or removal may insure a better balanced and over-all more efficient research program.

### Benefit Sensitivity of Individual Activities

This approach is somewhat different from the previous suggestion. Here we ask the question, "How much variation in the benefit coefficient of each activity would be required to induce a change in the optimum program?" (Rensi and Claxton 1972). These results may be useful in directing additional effort into data validation. They may also be useful in suggesting research areas where alternative proposals would be valuable.

### Additional Proposals for Activities

The validity of the entire analysis depends upon having available a large number of possible activities. Analysis may indicate that increases in resources would not result in a modified program. This condition may indicate a dearth of available proposals or a gap in the cost range of proposals. In either case, it would be helpful to increase the number or diversity of available proposals.

## SUMMARY

Claxton, H. Dean, and Giuseppe Rensi.
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This report describes an analytical procedure to assist in management decision-making for a government research program. It proposes a model that, with its corresponding framework for data collection, provides a comprehensive means of considering many vital details of organization structure and operation.

t also provides the necessary flexibility for modifi-ation as learning advances and the organization is nodified. The model provides a foundation for the optimization and analytical techniques described.

The objectives, activities, and restrictions of a government research organization are first considered, and a conceptual framework established. The major aspects that distinguish research from other forms of productive activities are examined at length. From his conceptual framework, the characteristics and potential uses of a management information system are suggested.

The proposed analytical procedure for formulating and evaluating a research program consists of two phases: (a) acquiring and validating information, and b) using information in decision-making. In the first phase, data are collected, updated, and cross-checked. n the second phase, the data are converted into a form useable for decision-making. Some of the operations can be designed to take advantage of automatic data processing capabilities.

Most of the problems associated with decision-making in research are considered by the model, analytical methods, and data reduction techniques described. A carefully built data base coupled with the mathematical modeling and programing techniques exemplified in the appendixes can provide the research administrator with an effective and powerful analytical tool.

Computer programs developed to expedite data processing according to the specifications of the model and to perform optimization and analysis are described in a companion report, *A Data Collection and Processing Procedure for Evaluating a Research Program,* published as USDA Forest Service Research Paper PSW-81.

# APPENDIX

## A - Mathematical Formulations of Research Planning Problems

This appendix offers examples of mathematical formulations of planning problems in research. Several features that present a particular interest from the viewpoint of model building are discussed. For clarity of exposition and in order to avoid a plethora of symbols each feature is described separately as a potential refinement of a basic optimization model. The basic optimization model is outlined in the first example. The second example considers an extension of the primordial model to incorporate several heterogeneous research activities. The mathematical modeling of multidimensional benefits and the symmetrical case of multidimensional costs are examined in the third and fourth examples, respectively. The fifth example offers a mathematical statement of the problem of output interdependence, while the feature of time streams of costs and benefits is treated in the sixth. Finally, the seventh example demonstrates a formulation of the problem of uncertainty. The purpose of this discussion is to better assess the implication of each feature in terms of complexity of the analysis and information requirements. Once the basic model and each additional feature are thoroughly understood as separate building blocks it won't be difficult to formulate a model of research planning including any combination of the features outlined.

### 1. One Homogeneous Research Activity

Let the activity carried out by a research organization be represented by the production function

$$y = F(x)$$

in which y is a homogeneous output variable, say, 'benefit' and x is a homogeneous input variable, say, 'cost.' The production function is a set of maximum points. That is to each input point it associates the maximum output obtainable from it. Assume that a fixed budget B can be spent on research. Then the problem can be expressed as:

$$\begin{aligned} &\max && y \\ &\text{subject to} && x \leqslant B \\ &\text{and} && y = F(x) \end{aligned}$$

A notion of optimum management policy is unambiguously defined in this formulation. A slight variant of it is

$$\begin{aligned} &\max && (y-x) \\ &\text{subject to} && x \leqslant B \\ &\text{and} && y = F(x) \end{aligned}$$

in which net instead of gross benefits are considered in management choices. The shortcomings of these

formulations are obvious. The definitions of input, output and function do not imply procedures for measuring them. They are unoperational. The causality relation between cost and benefit is assumed and not explained. And the definition of the production function as a locus of optimum points partially begs the question of the best decision. The decision problem is stated in a semi-tautological way.

**2. Several Research Activities**

Presumably the research activity carried out within an organization is not homogeneous, monolithic, and undifferentiated. A plurality of lines can be identified, each line characterized by different inputs, outputs, and relations between inputs and outputs. For example, compare a research on the microscopic properties of a species of wood and a research on the engineering properties of that species of wood when used as a construction material. By and large the two research lines have different input requirements in terms of scientific skills, equipment, and materials. Also the results are expected to be qualitatively and quantitatively different. One can then envisage a research outfit as a set of distinct research activities—each one of them characterized by a different production function. Assuming that inputs and outputs can be expressed in the same aggregate units of 'cost' and, respectively, 'benefit' for all of the N activities carried out then the production function of the j-th activity can be specified as

$$y^j = F^j(x^j) \; ; \; j = 1, \ldots, N$$

Given a fixed budget, as in the previous case, the management decision problem can be stated as:

$$\max \quad \sum_j y^j$$

$$\text{subject to} \quad \sum_j x^j \leqslant B$$

$$\text{and} \quad y^j = F^j(x^j) \; ; \; j = 1, \ldots, N$$

If net benefit, instead of gross, were the appropriate performance criterion, then the problem can be restated as

$$\max \quad \sum_j (y^j - x^j)$$

$$\text{subject to} \quad \sum_j x^j \leqslant B$$

$$\text{and} \quad y^j = F^j(x^j) \; ; \; j = 1, \ldots, N$$

Whether net benefit instead of gross benefit is used as optimality criterion depends on the possibility of using inputs in alternative ways. These alternative uses may include savings on consumption as well as alternative investment outlets. The solution of this type of decision problem involves the determination of the optimum set of values $(x^j; j = 1, ..., N)$ i.e., the set $(x^j; j = 1, ..., N)$ at which benefit is largest. The technique of solution depends on the form of the functions $F^j$. If $\sum_j F^j$ satisfies certain "convexity" properties and the budget constraint is expressed as an equality,[5] then calculus techniques, such as the method of Lagrangian multipliers, provide the mathematical conditions that the solution must satisfy. For the solution to make any sense at all, the magnitude of B must be consistent with a set of non-negative vectors $(x^j ; j=1, ..., N)$. If no particular restrictions are imposed on the form of the $F^j$'s, then solution methods may be provided by iterative techniques. For instance, in a dynamic programing approach a recursion relationship expressing the optimality principle can be stated as

$$G^j(x^1, \ldots, x^N ; B) = \max_{x^j} [(y^j - x^j) + G^{j-1}(x^1, \ldots, x^N ; B - x^j)]$$

where

$$y^j = F^j(x^j) \quad \text{and} \quad O \leqslant x^j \leqslant B \; ; \; j = 1, \ldots, N$$

The relationship states that independently of the amount $x^j$ of budget allocated to the j-th activity, the remaining portion of the budget $B\text{-}x^j$ must be distributed in an optimal way (in terms of net benefit) among the remaining (j-1) activities. As a final remark on this type of model note how, depending on the nature of the inputs and outputs of each activity, the operational specification of $y^j$, $x^j$ and $F^j; j=1, ..., N$ may call for a prohibitive amount of information.

**3. Multidimensional Benefits**

If a research organization has several objectives whose degree of achievement is measured in different units, then it may be desirable to define benefit as a vector. Suppose that there are K-objectives. Then the output of the j-th activity can be specified as

$$\underline{Y}^j = (y_1^j, \ldots, y_K^j)$$

Consequently the production function of the j-th activity is a vector function

[5] This is the classical example of optimum allocation described in textbooks of mathematical economics. See, for example, Hicks (1946).

$$\underline{Y}^j = \underline{F}^j(x^j) = \begin{matrix} F_1^j(x^j) \\ F_2^j(x^j) \\ \vdots \\ F_K^j(x^j) \end{matrix}$$

The specification of multidimentional benefits raises a number of difficulties concerning the definition of an ordering of vectors. The solution of any decision problem is contingent upon the possibility of ranking alternatives according to some criterion and a vector criterion cannot generally be ordered. This problem can be solved by introducing a function that 'scales' the benefit vector, i.e., a mapping from the K-dimensional space to the real line. A special case of this function is a linear function

$$\underline{W}' \underline{Y} = \sum_k w_k y_k$$

where $W = (w_1, \ldots, w_K)$ is a vector of weights specifying some hierarchical scale among the K benefit dimensions. In most instances, specifying quantitative equivalences between different objectives involves subjective determinations.

The decision problem can be stated in this case as

$$\begin{aligned} \max \quad & \sum_j (\underline{W}'\underline{Y}^j) \\ \text{subject to} \quad & \sum_j x^j \leqslant B \\ \text{and} \quad & \underline{Y}^j = \underline{F}^j(x^j) \; ; \; j = 1, \ldots, N \end{aligned}$$

Another way to avoid the problem of indeterminacy or vector ranking in the multidimensional benefit case consists in selecting one benefit dimension to be maximized while setting minimum standards of achievement for the other benefit dimensions. This requires a redefinition of the activity production functions and a new specification of constraints. The problem can be restated as:

$$\begin{aligned} \max \quad & \sum_j y_1^j \\ \text{subject to} \quad & \sum_j x^j \leqslant B \\ & \sum_j y_k^j \geqslant \bar{y}_k \; ; \; k = 2, \ldots, K \\ \text{and} \quad & \\ & y_1^j = H^j(y_2^j, \ldots, y_K^j ; x^j) \; ; \; j = 1, \ldots, N \end{aligned}$$

in which $y_1$ is the benefit dimension selected as maximand, $\bar{y}_2, \ldots, \bar{y}_K$ are the prescribed minimum requirements for the other benefit dimensions, and $H^j$ are production functions with outputs $y_1^j$ which include $y_2^j, \ldots, y_K^j$ as parameters. The latter statement of the problem may be considered a subcase of the multiple input class of models to be treated in the next example.

**4. Several Inputs**

Instead of one-dimensional, all comprehensive measure of disutility one may specify several such measures. Hence an input vector $\underline{X} = (x_1, \ldots, x_M)$ is substituted for the scalar x. Introducing an M-dimensional input vector requires a reformulation of the constraints in the statement of the decision problem. Let the vector $b = (b_1, \ldots, b_M)$ specify upper bounds on the availability of the inputs. Let $\underline{P} = (p_1, \ldots, p_M)$ define the expenditures per unit for the M inputs, then the decision problem can be formulated as follows

$$\begin{aligned} \max \quad & \sum_j y^j \\ \text{subject to} \quad & \sum_j x_i^j \leqslant b_i \; ; \; i = 1, \ldots, M \\ & \sum_j (\underline{P}'\underline{X}^j) \leqslant B \\ \text{and} \quad & y^j = F^j(\underline{X}^j) \; ; \; j = 1, \ldots, N \end{aligned}$$

in which $\underline{P}'\underline{X}^j = \sum_i p_i x_i^j$ represents the expenditure for activity j. The upper bound constraints need to be explicitly specified only for inputs whose availability is limited.

**5. Output–Interdependence**

It may be appropriate in certain instances to recognize explicitly the fact that the outcome of one research activity may depend on the outcome of other research activities. There are several ways in which this dependence can be specified in the definition of the production function for an activity. In general:

$$y^j = F^j(x^j ; (y^s ; s = 1, \ldots, N; s \neq j))$$

i.e., the output of an activity is assumed to result from the interactive combination of the inputs of that activity and the outputs of the remaining ones. In some cases it may be warranted to hypothesize functional separability (Leontief 1947) between the input of activity j and the outputs of the other activities in the j-th activity production function.

Accordingly

$$y^j = F^j(x^j, G^j(y^s ; s = 1, \ldots, N; s \neq j))$$

For example

$$y^j = F^j(x^j) \cdot G(y^s / \bar{y}^s)$$

states that the input productivity of activity j varies in proportion to the success in activity s measured as a fraction of a fixed output level $\bar{y}^s$. In other cases it may be appropriate to assume that in order for activity j to be carried out at all a certain level of output $\bar{y}^s \geqslant 0$ must be reached in the other activities s = 1, ..., N, $s \neq j$. This situation can be represented by

$$y^j = F^j(x^j) \cdot G^j(\bar{y}^s ; s = 1, \ldots, N ; s \neq j)$$

$$G^j(\bar{y}^s; s = 1, \ldots, N; s \neq j) = \begin{cases} 1 \text{ if, for all s, } y^s \geqslant \bar{y}^s \\ 0 \text{ otherwise} \end{cases}$$

## 6. The Time Dimension

As time is introduced in the analysis, the inputs and outputs of a research activity are treated as time streams. Let

$$\underline{X}^j = \{ x_1^j, x_2^j, \ldots \} \quad \text{and} \quad \underline{Y}^j = \{ y_1^j, y_2^j, \ldots \}$$

represent streams of yearly inputs and outputs, respectively, for the j-th activity. Assuming that each yearly flow $y_t^j$, t = 1, 2, ..., is measured in dollars, the present value of the output stream $Y^j$ can be defined as

$$y^j = \sum_t y_t^j \, d^t$$

where

$$d^t = (1 + \rho)^{-t}$$

and $\rho$ is an appropriate rate of interest. For every $\underline{X}^j$ consider the highest present value of all output streams $\underline{Y}^j$ that could be produced from $\underline{X}^j$. The pairs of $y^j$ $\underline{X}^j$ so defined constitute the 'time production function' for the j-th activity, namely,

$$y^j = F^j(\underline{X}^j)$$

The time production function so defined depends on the fixed parameter $\rho$. To express this dependence the function can be stated as

$$y^j = F^j(\underline{X}^j ; \rho)$$

In some cases one may be justified in assuming t the value of the output stream of a research activ *discounted to the time of successful completion the activity* is a constant. This assumption co sponds to the notion that the output of a resea activity is a specific scientific target. When evalua from the vantage point of the present, the poten repercussions of a specified scientific achievement a technological innovation have a fixed magnitud Define this constant value as $y_*^j$, the 'potential' activity j. What varies as a function of the in stream is the time of completion of the resea activity. Let $t_j$ be the time of completion for activ j. Then

$$t_j = G^j(\underline{X}^j)$$

and

$$y^j = y_*^j \, d^{t_j} = y_*^j \, d^{G^j(\underline{X}^j)}$$

represent simple statements of the production c straints. When time is introduced in the statemen the decision model, budget constraints and c straints on other limiting factors must be specified every year of a future time horizon of appropriat chosen length H. The decision problem could ther specified as

$$\text{Max} \quad \sum_j y^j$$

$$\text{subject to} \quad \sum_j x_t^j \leqslant B_t \; ; \; t = 1, \ldots, H$$

$$\text{and} \quad y^j = F^j(\underline{X}^j \; ; \; \rho)$$

where $B_t$ is the budget constraint for year t. Here, well as in example 5 simple one-input, one-outp activity production functions have been presented simplicity of exposition and economy of symbo The extension to several outputs and inputs dim sions along the lines suggested in Examples 3 and respectively, can be easily made.

## 7. Uncertainty

A decision model may contain assumptions c cerning the problem of uncertainty. This is especia

[6] What is assumed here is a time schedule of implementat and diffusion of the socio-economic consequences of scientific achievement independent of the amounts of inp invested in the research phase; that is, the research outfit control only on the production of research results and not their adoption in productive uses.

appropriate in a research activity in which input-output relations cannot be known with certainty, or if future constraint bounds may not be specified with perfect knowledge. In either case stochastic mechanisms can be included in the model by substituting

$$y^j = F^j(x^j) \qquad j = 1, \ldots, N$$

with $$y^j = G^j(F^j(x^j), u^j) \; ; P^j(u^j)$$

$$j = 1, \ldots, N$$

and $$\sum_j x^j \leqslant B$$

with $$\sum_j x^j \leqslant H(B, v) \; ; Q(v)$$

where G and H are functions to be specified and $u^j$ j=1, ..., N, and v are random variables with probability distributions $P^j(u^j)$, j=1, ..., N, and $Q(v)$ respectively. In the case when the time variable appears in the model it may be appropriate to consider time vectors of random variables

$$\underline{U}^j = (u_1^j, u_2^j, \ldots) \; ; j = 1, \ldots, N$$

and their joint probability distributions $\Omega(\underline{U}^j)$.

As a specific example, consider the stochastic production function

$$y^j = F^j(x^j) \cdot u^j; \; O \leqslant u^j \leqslant \infty; \; E(u^j) = 1$$

Here only the range and the expected value of the probability distribution of $u^j$ are specified. This stochastic representation of the production function for the j-th activity reflects the fact that for a given value $x^j$ of the input variable, the output obtained is not precisely $F^j(x^j)$ but more or less $F^j(x^j)$ i.e., $F(x^j)$ multiplied by a variable whose expected value is one. If $u^j > 1$ the success of allocating $x^j$ to the j-th research activity will have been greater than 'expected' and vice versa.

Instead of 'objective' probability distributions with parameters to be estimated from empirical data, one can specify subjective measures of confidence to be used as the certainty equivalence factors mentioned toward the end of the section on Activities and Programs.

## B - Zero-One Integer Programing Optimization

This appendix describes how the zero-one integer programing optimization technique can be used to select a best research program among several alternatives. At the same time it demonstrates how the data identified and classified in the section Acquisition and Validation of Information can be used as input for the optimization model.

Consider the list of activities which are candidates for inclusion into a research program. Assume the total number of these activities to be N. Let each activity be labeled with an index number i, where i goes from 1 to N. Define the following measures for each activity:

$T_C$ = completion time, i.e., number of remaining budget years for the research activity.
$T_B$ = beginning implementation time, i.e., number of years from the research inception after which the results of the research will be first applied for useful purposes
$T_E$ = ending implementation time, i.e., number of years from the research inception after which the application of the research results will be discontinued because of obsolescence
$P_C$ = chances of successful completion of the research activity
$P_I$ = chances of successful implementation of the activity, given its successful completion
$x_t$ = research budget for year t, where t goes from 1 to $T_C$
$y_t$= net benefit, i.e., dollar benefit minus implementation cost for year t where t goes from $T_B$ to $T_E$
r = interest rate to be used in the discount formula
w = extraeconomic adjustment factor

Given these information items for a research activity the benefit of the activity can be calculated as

$$b = \left( \sum_{t=T_B}^{T_E} y_t (1+r)^{-t} \right) P_c \, P_I \, w - \sum_{t=1}^{T_C} x_t (1+r)^{-t} \qquad (1)$$

Let the benefit for activity i, calculated according to formula (1), be indicated as $b_i$

Suppose M constraints are specified for the organization, labeled j=1, 2, 3, ..., M. Let $U_j$ represent an upper bound measure of the j-th constraint and $a_{ij}$, i=1, ..., N, measures of how research activity i, i=1, ...,

N is affected by the j-th constraint. With reference to the section, Constraints, four types of constraints can be considered, namely limited resource constraints, minimum performance constraints, internal allocation constraints, and interdependence constraints. Consider instances of each type of constraint.

**1. Limited Resource Constraints**

Let constraint j reflect a limitation on budget money in year t. If the expected budget for the research organization in year t is expected to be $X_t$ and the planned money expenditure for research activity i in year t is $x_{it}$ then, for constraint j, $U_j = X_t$ and $a_{ij} = x_{it}$; i=1, ..., N. Similarly let constraint j represent limited availability of a certain physical facility. If H is the number of weekly hours when the facility is available and $h_i$ is the number of weekly hours requirement by activity i, then constraint j is defined by $U_j = H$ and $a_{ij} = h_i$; i=1, ..., N.

**2. Minimum Performance Constraints**

Let constraint j define the requirement that the organization achieve at least G units of a certain special goal. Let $g_i$ represent the number of units of the goal that activity i is expected to achieve. In this case $U_j = -G$ and $a_{ij} = -g_i$; i=1, ..., N.

**3. Internal Allocation Constraints**

Let constraint j express the requirement that at least $X_D$ dollars be spent on an administrative subdivision D of the organization in year t. Then $U_j = -X_D$ and $a_{ij} = -x_{it}$ if activity i falls under the jurisdiction of subdivision D, $a_{ij} = O$ otherwise, i =1, ..., N.

**4. Interdependence Constraints**

Let constraint j specify the fact that activities belonging to a specified subset S are mutually exclusive. Then one may set $U_j = 1$ and $a_{ij} = 1$ if activity i belongs to S and $a_{ij} = O$ if activity i does not belong to the specified subset.

The information on benefits and constraints as outlined above can be summarized in a compact form as shown in *figure 4.*

Given a set of N activities

$$T = [1, 2, ..., N]$$

any subset of T represents a program. For instance

$$P = [i_1, i_2, ..., i_K]$$

where $K \leqslant N$ is such a program. The benefit of a research program so defined is the sum of the benefits of the activities included in the program, i.e.,

$$B = \sum_{i \epsilon P} b_i = \sum_{k=1}^{K} b_{i_k}$$

Similarly the program's requirement of constraint j is the sum of the requirements for constraint j of the activities included in the program, namely

$$R_j = \sum_{i \epsilon P} aij = \sum_{k=1}^{K} a_{i_k j}$$

Given the upper bounds on the constraints, $U_j$; j=1, ..., M, a program P is called feasible if, for all j, j = 1, ..., M

| Activities | Benefits | Constraints | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | . . . | M |
| 1 | $b_1$ | $a_{11}$ | $a_{12}$ | $a_{13}$ | . . . | $a_{1M}$ |
| 2 | $b_2$ | $a_{21}$ | $a_{22}$ | $a_{23}$ | . . . | $a_{2M}$ |
| 3 | $b_3$ | $a_{31}$ | $a_{32}$ | $a_{33}$ | . . . | $a_{3M}$ |
| 4 | $b_4$ | $a_{41}$ | $a_{42}$ | $a_{43}$ | . . . | $a_{4M}$ |
| . | . | . | . | . | | . |
| . | . | . | . | . | | . |
| . | . | . | . | . | | . |
| . | . | . | . | . | | . |
| . | . | . | . | . | | . |
| N | $b_N$ | . | . | . | | $a_{NM}$ |
| Constraint upper bounds | | $U_1$ | $U_2$ | $U_3$ | . . . | $U_M$ |

**Figure 4**—Example of information requirements for a zero-one integer programing formulation of research planning.

$$R_j \leq U_j$$

.e., if none of the program constraint requirements xceeds the constraint availability bound. Conversely program P is unfeasible if it violates at least one onstraint, i.e., if for at least one j

$$R_j > U_j$$

The zero-one integer programing approach to electing an optimum research program consists in inding a program P* which yields the largest benefit mong all feasible alternatives. In other words one vants to find P* such that

$$\text{(a)}\quad R_j(P^*) \leq U_j \; ; j = 1, \ldots, M$$

nd

$$\text{(b)}\quad B(P^*) \geq B(P)$$

vhere P is any feasible alternative program. Anal-gously the problem can be specified by defining for ach activity i; i=1, ..., N an index variable

$$I_i, i=1, \ldots, N$$

ndicating whether activity i is included in a program r not. If research activity i is included in the rogram examined $I_i$=1, otherwise $I_i$=O.

The problem can then be stated as follows:

$$\max_{I_i} \quad B = \sum_{i=1}^{N} b_i \; I_i$$

$$\text{subject to} \quad \sum_{i=1}^{N} a_{ij} I_i \leq U_j \; ; \; j=1, \ldots, M$$

To understand what the solution of the problem ntails consider the following elementary solution lgorithm

(i) List all possible alternative research programs, i.e., all subsets $P \subseteq T$
(ii) For each alternative program calculate the total benefit and constraint requirements
(iii) Discard unfeasible programs
(iv) Of the remaining programs select the one with the largest benefit as best.

This is a perfectly valid solution method in the sense that it will always produce the best program. However it is a computationally inefficient method especially if the possibility set consists of a large number of activities. The reason for this is that if N is large there is an extremely large number of programs to be screened one by one for feasibility and optimality. In fact given N possible activities in the candidate list there are $\binom{N}{1}$ one-activity programs, $\binom{N}{2}$ two activity programs, ... $\binom{N}{N}$ N- activity programs.[7] Summing all these possibilities one obtains

$$\sum_{K=0}^{N} \binom{N}{K} = 2^N$$

Noting that for N=10, $2^N$ equals 1024 and for N=100, $2^N$ equals approximately $10^{30}$ one can readily appreciate the magnitude of the computational effort involved and the necessity for an efficient solution algorithm.

For the purposes of this study a fairly satisfactory zero-one integer programing solution method has been assembled and experimented with on a variety of numerical problems. A detailed account of the algorithm and its properties is beyond the scope of this presentation. It is a branch and bound type of algorithm and it applies theoretical results developed by Balas (1965) and Glover (1965) with modifications to take advantage of the special structure of the research activity selection problem.

[7] $\binom{N}{K}$ is the number of combinations of N objects taken K at a time. $\binom{N}{K} = \frac{N!}{K!\,(N-K)!}$

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An analytical procedure to help management decision-making in planning government research is described. The objectives, activities, and restrictions of a government research organization are modeled in a consistent analytical framework. Theory and methodology is drawn from economics and mathematical programing. The major analytical aspects distinguishing research from other forms of economic activities are examined. The characteristics and potential uses of a management information system are outlined.

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*Retrieval Terms:* research administration; decision making; management planning; analytical procedure; mathematical models.

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Forest and Range
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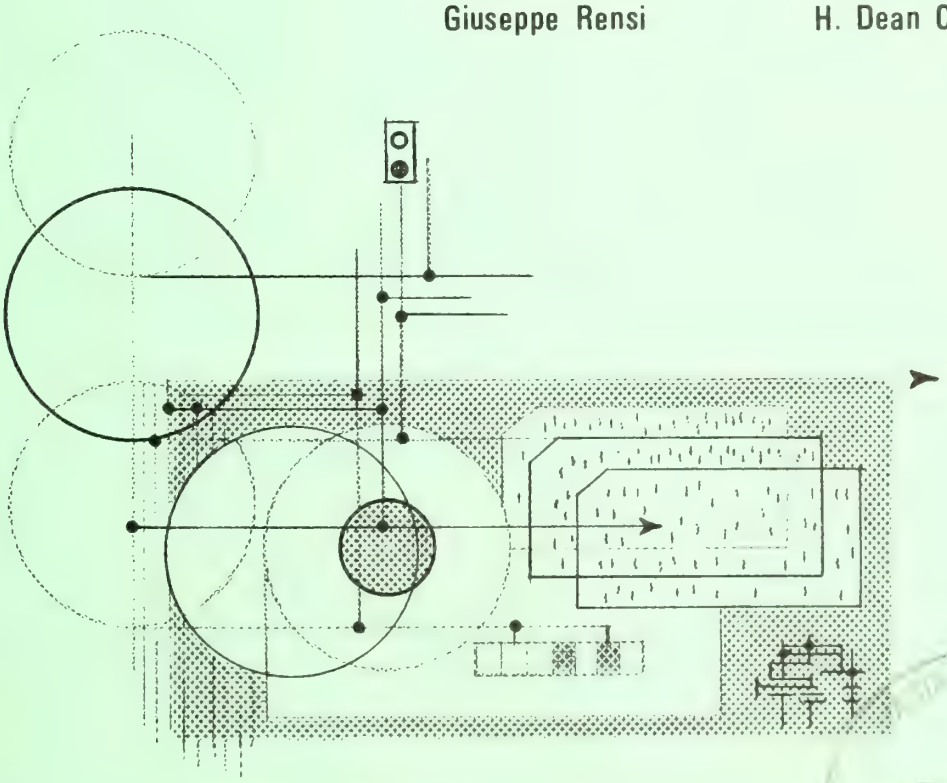
# A DATA COLLECTION AND PROCESSING PROCEDURE for evaluating a research program

Giuseppe Rensi H. Dean Claxton



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# FOREWORD

Evaluating proposals for inclusion in a research program is an important, continuing, and difficult decision process for the research administrator. He usually decides on the basis of intuition and experience. Typically, only a small amount of data and analysis are available to him before proposals are selected and molded into a research program.

Recognizing the potential for improving this process, the consistency and perhaps the quality of the decisions, the Forest Service started both theoretical and empirical studies in 1967. Theoretical work was done at the Pacific Southwest Forest and Range Experiment Station in cooperation with the University of California, Berkeley. The U.S. Forest Products Laboratory at Madison, Wisconsin, cooperated by providing data for both theoretical and practical work.

The procedures reported in this paper were developed by the Station in cooperation with the University of California, Berkeley.


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Decisions concerning the choice of research projects have historically been based mostly on the intuition, knowledge, and wisdom of the administrator responsible for deciding. The complex nature of these decisions is readily recognized, but the traditional tools for reducing complex decisions, including the collection and analysis of data, are rarely applied to the problem.

With increasing public awareness of research costs and potential gains from research results, the need for greater internal consistency and rational planning is becoming more apparent than ever before. Increasing availability of large-scale data storage and processing equipment offers an opportunity to improve consistency and rationality in the research planning process.

In recognition of these needs and capabilities, the Forest Service started a series of special studies of the problem. A considerable amount of theoretical and empirical work was carried out to develop an analytical procedure for evaluating and planning research programs in the context of a government research organization. This analytical procedure is based on a descriptive model of a research organization. The definitions and assumptions underlying the model are found in a companion report *An Analytical Procedure to Assist Decision-Making in a Government Research Organization,* by H. Dean Claxton and Giuseppe Rensi, published by the Pacific Southwest Forest and Range Experiment Station, Berkeley, California, as USDA Forest Service Research Paper PSW-80.

The analytical procedure developed can be most useful when coupled with computer programs or techniques for data storage and manipulation. It could not possibly be used without computer implementation.

This report describes a set of computer programs and subroutines that will partially fulfill the information processing requirements of this analytical procedure.

The over-all cycle of information gathering, processing, and utilization—as specified by the procedure—consists of these five steps:

1. Specification of the relevant data.
2. Assembly and storage of information.
3. Periodical updating of information.
4. Cross-checking of information.
5. Conversion of information into a form usable for decision-making purposes.

The programs documented in this paper were developed to carry out data manipulations required in steps 2, 3, and 5. From a functional viewpoint, the operations performed in the three steps can be summarized as follows:

I Input data
II Matrix generation
III Input and generated data report
IV Zero-one integer programing optimization
V Analysis reports using optimization.

Operation I involves coding and formatting information about the research activity in a form acceptable to data processing media.

Operations II and III produce a schematic description of the status of a research organization at a given time, including: (1) Definition and measurement of performance criteria; (2) definition and measurement of limiting factors; and (3) definition and numerical description of research projects.

In operations IV and V, a zero-one integer programing algorithm uses the information matrix produced in operation II to obtain an optimum set of binary decisions concerning each potential research activity. A "yes" decision on a research project may be interpreted as a recommendation that the project be carried out in the next planning period; the opposite holds for a "no" decision. Operation V, in particular, provides options to use the optimization routine in a repetitive fashion to analyze the sensitivity of optimum decisions to variations in any of the parameters of the problem. Simulated responses to a variety of policy decisions can be thereby explored.

The programs and routines described in this paper do not account for all the information processing tasks required in the analytical approach to research

evaluation and planning. Some of the steps in that approach, for example, "cross-checking of the information," do not lend themselves to automated execution. Therefore, these computer programs do not form an integrated, self-contained research planning software package. More accurately the software elements described here can be considered a means to utilize automated processing facilities in those phases of research planning that require routine manipulations of large amounts of data.

# INPUT DATA

Information is assembled and structured in a format appropriate for automated processing. Two steps are involved: data collection and data formatting.

## *Data Collection*

The collection of data is done by means of three reference lists and an appropriately designed data sheet. One such data sheet is used for each proposed research project.

Reference List 1 assigns to each research project in the organization (a) an identification code number; and (b) a title. The identification code is chosen among the numbers ranging from 1 through 999. Different projects should be assigned different code numbers. Different versions of the same research project corresponding to diverse levels of resource outlays and utility contributions should be assigned different code numbers and documented on separate project data sheets.

Reference List 2 contains a set of resources other than budget funds which are available in limited short-run supply to the research organization. The use of these resources is shared by the projects which require them. Examples of such resources may be laboratory space, computing facilities, and personnel with special skills. For each resource entered, Reference List 2 specifies (a) an identification code number; (b) a description of the resource; and (c) a unit of measure for the resource's use.

Reference List 3 specifies a set of achievement criteria other than dollar benefits. For every performance criterion entered, Reference List 3 indicates (a) an identification code number; (b) a description of the performance criterion; and (c) a unit of measure of such performance criterion. Examples of performance criteria other than dollar benefits may be air pollution abatement, and low cost housing.

A project data sheet consists of three sections: (1) project identification items; (2) project resource outlays, namely, money expenditures and other limited resources use; (3) expected utility contributions, namely, economic benefits and other performance measures.

1. Section One: Identification
   - 1.1 Identification Number and Title
     For the identification code number, consult Reference List 1.
   - 1.2 Research Leader
     Name of the researcher in charge of the project.
   - 1.3 Expected Research Output.
     This item refers to the "research phase" of the project. The research phase may be followed by an "implementation phase," i.e., the conversion of research results into socio-economically useful applications. The implementation phase may or may not be carried out by the research organization. Only when the implementation phase is part of the research project do expected research output (item 1.3) and application (item 3.1) coincide. This can happen when a project involves technology development, or research extension. If a project deals exclusively with surveys, classifications, testing of hypotheses, or formulations or verifications of theories, then item 1.3 and 3.1 do not coincide.
2. Section Two: Resource Outlays
   - 2.1 Expenditure Table
     - –Year
     - –General Expenditures
     - –New Equipment Expenditures

     Number the years from 1 through T; T is the project's expected duration, measured in years. General expenditures include salaries, overhead, and current operating expenses. New equipment expenditures refer to procurement costs for equipment required exclusively by the project. Such is the case, for instance, when the project involves equipment development. Yearly

cash flows should be recorded to describe the type of transaction planned, e.g., lump payment, installment payments, rentals.

2.2 Other Resource Outlays Table

–Resource Number
–Amount Required

Resource number indicates the identification code assigned in Reference List 2. Amounts used are measured in the units established in Reference List 2.

2.3 Probability of Successful Completion

This item expresses in percent the likelihood that the expected research output entered into 1.3 is achieved within the time and with the resources specified in 2.1 and 2.2.

3. Section Three: Utility Contributions

3.1 Application Number and Title

Applications are consequences of research which have measurable public value. When several applications are listed under the same project use sequential numbers starting from 1.

3.2 Benefit and Extra Cost per Unit

Items 3.2 through 3.4 apply when the value of the application examined has an economic dimension, i.e., can be expressed in dollar terms. Such is the case for most technological changes, i.e., product or process innovations. Benefit per unit expresses, in dollar units, the gross (net) added value per unit of product in a product innovation or the gross (net) cost saving per unit of production in a process innovation. If the net figure is entered, do not record extra cost per unit. If gross benefit per unit is reported, then extra cost per unit must be entered as well. Extra cost per unit measures the unit cost increase required to achieve the gross benefits per unit stated. In process innovations, cost savings in some phases of the production process may be accompanied, and partially offset by cost increases in other phases.

3.3 Industrial Implementation Schedule

–Year
–Volume
–Percent Affected

This table describes the time path of diffusion of the innovation described in item 3.1. Years are counted to begin from the project's inception point, e.g., year t indicates the t-th year since the project started. Volume equals total production in a given year. Percent affected estimates the fraction of total production affected by the innovation in the same year.

3.4 Benefit Accrual Schedule

–Year
–Added Benefit
–Extra Cost

This item is used instead of item 3.2 and 3.3 when both are not available. If items 3.2 and 3.3 are appropriately filled in, disregard item 3.4. Years are numbered beginning from the project inception. Added benefit and extra cost specify total dollar estimates in a given year. When both added benefit and extra cost arrays are entered, "benefit" indicates gross benefit; when the extra cost row is left empty, "benefit" is interpreted as net benefit.

3.5 Other Performance Measures Table

–Criterion Number
–Contribution

Criterion number identifies the performance criterion code as specified in Reference List 3. Contribution represents a measure of the project's expected performance according to that criterion. Use the unit measure in Reference List 3.

3.6 Adjustment Fraction

The adjustment fraction expresses, in percent, the rate at which the net dollar benefit of the project should be increased (discounted) to take into account desirable (or undesirable) aspects not properly reported under other items. Examples of such aspects may be positive or negative effects on income distribution, positive or negative effects on the quality of the environment not quantified otherwise, or lower priority of the project when similar research is carried out by other individuals or institutions.

3.7 Probability of Successful Implementation

This item shows the likelihood, expressed in percent, that the results generated will be converted into useful applications as specified in items 3.1 through 3.5.

3.8 References and Comments

Outline the sources of information and assumptions underlying the construction of estimates.

Appendix A illustrates examples of Reference Lists 1, 2, 3, and three project data sheets.

## Data Formatting

Data formatting consists of specifying the format in which information data sheets are transferred onto punch cards. The sequencing of cards and the information content of each card in the sequence must be indicated. A complete card deck consists of three parts: (1) control cards; (2) project data cards; and (3) organization data cards.

### Control Cards

Control cards contain instructions concerning the specification of basic constraints. "Basic" constraints are those constraints whose coefficients may be read directly from project data sheets. The three categories of basic constraints are: (1) Budget constraints; (2) Limited resources constraints; and (3) Performance target constraints.

A card deck sequence is as follows:

1. Basic constraints control card
2. Budget years control card(s)
3. Limited resources control card(s)
4. Performance target control card(s)

The control cards and deck setups outlined above allow a considerable degree of flexibility in the specification of basic constraints and the corresponding interaction with other data cards. Project data cards may contain information about constraints in any of the three categories of basic constraints not being used in the analysis. For example, information may be available on 20 limited resources, but the analyst wants to consider only five as actual constraints. Control cards allow him to disregard information about the remaining 15 constraints without modifying the information base contained in project data cards.

Appendix B details the coding instructions for control cards.

### Project Data Cards

Information about a single research project is organized in a sequence of project data cards. The information recorded is the set of coefficients of the basic constraints and the benefit information. Both are taken directly from a project data sheet or constructed from the information on the sheet. Each data block of project data cards is arranged in this card sequence:

1. Project identification card
2. Project parameter card
3. General expenditures card(s)
4. New equipment expenditures card(s)[1]
5. Limited resources card(s)[1]
6. Limited resources use card(s)[1]
7. Application title card
8. Application parameter card
9.* Benefit per unit card
10.* Production volume card(s)
11.* Percent acceptance card(s)
12. Performance criteria card(s)[2]
13. Performance measures card(s)[2]

If more than one application is documented, card sequence 7 through 13 is repeated for each application. Cards 9*, 10*, 11* are used only when items 3.2 and 3.3 are available in the project data sheet. This condition is called *Benefit Documentation Case One.* When only item 3.4 is recorded in the project data sheet (called *Benefit Documentation Case Two*), the starred card sequence is replaced by the sequence:

1. Added benefits card(s)
2. Extra cost card(s).

When only the "added benefit" row of item 3.4 is available in the project data sheet *(Benefit Documentation Case Three),* the starred card sequence is replaced by:

Net benefit card(s).

Card sequence 1 through 13 has been designed to reflect the structure of the project data sheets.

Detailed coding instructions are in Appendix B.

### Organization Data Cards

The organization data cards contain the information necessary to specify contraints of the organization. The bounds or limits on the basic constraints are stated first. The card sequence for basic constraint limits is:

1. Budget level card(s)[3]
2. Limited resource level card(s)[3]
3. Performance level card(s).[3]

Added next is information on "added" constraints, which can be of three types: (1) Allocation constraints; (2) Interdependence constraints; and (3) Miscellaneous constraints. Added constraints can be

---

[1]These cards can be omitted or included depending on instructions in project parameter card.

[2]These cards can be omitted or included depending on instructions in application parameter card.

[3]Inclusion or omission of these cards depends on instructions input into the basic constraints control card.

specified independently of the information found in the project data sheets. The card deck organization is:

Allocation parameter card
Allocation project card(s)

---

Interdependence parameter card
Interdependence project card(s)

---

Miscellaneous parameter card
Miscellaneous project card(s)
Miscellaneous coefficient card(s)

The order in which the three added constraint types are input is unrestricted. For example, two allocation constraints, three interdependence constraints, and one miscellaneous constraint can be sequenced as follows: M, I, I, A, I, A. Given the added constraint type, however, i.e., A, I, or M, the card succession indicated must be respected. A separation card, i.e., a card with the character "9" punched across columns 1 through 80, must be interposed between project data cards and organization data cards. A termination card, i.e., a card with the character "−" punched across columns 1 through 80 must appear at the end of the complete deck. Detailed instructions as to the information content of each card are given in Appendix B.

To summarize, a complete deck is stacked as follows:

1. Control cards
2. First project data cards
   Second project data cards
   .
   .
   .
   N-th project data cards
3. Separation card
4. Organization data cards
5. Termination card.

The order in which project data blocks are entered does not matter as long as the cards within a data block are properly ordered. After the information has been transferred to a card deck according to the instructions here specified, it can be processed by means of program FILE and its associated subroutines. In the listing[4] of FILE, input sections pertaining to different card types are carefully enclosed between comment statements. This arrangement makes it expedient for the user to identify the program instructions that affects each card input. Two types of error messages can be produced during the execution of FILE. The first type of error occurs when the maximum number of projects allowed is exceeded or when the maximum number of constraints allowed is exceeded. These maximum limits have been set, tentatively, at 250 projects and 50 constraints. The second type of error consists of improper card sequencing. The corresponding error message reveals which card has been misplaced or assigned an improper identification code.

[4]A listing of computer programs and subprograms described in this report can be obtained by writing to the Director, Pacific Southwest Forest and Range Experiment Station, P.O. Box 245, Berkeley, California 94701.

# MATRIX GENERATION

As the data are processed by program FILE a basic information matrix is produced. This matrix represents the essential input for the optimization algorithms that characterize the two operations: Zero-One Optimization and Analysis Reports Using Optimization. The structure of the matrix can be illustrated in this way:

| | 0 | 1 | 2 | 3 | • | • | • | M |
|---|---|---|---|---|---|---|---|---|
| 1 | $V_1$ | $a_{11}$ | $a_{12}$ | $a_{13}$ | | | | $a_{1M}$ |
| 2 | $V_2$ | $a_{21}$ | $a_{22}$ | $a_{23}$ | | | | $a_{2M}$ |
| 3 | $V_3$ | $a_{31}$ | $a_{32}$ | $a_{33}$ | | | | $a_{3M}$ |
| • | • | | | | | | | |
| • | • | | | | | | | |
| • | • | | | | | | | |
| N | $V_N$ | $a_{N1}$ | $a_{N2}$ | $a_{N3}$ | | | | $a_{NM}$ |
| | | Inequality signs $\geqslant$, or =, or $\leqslant$ | | | | | | |
| | | $b_1$ | $b_2$ | $b_3$ | • | • | • | $b_M$ |

Column O of the matrix represents the values $V_i$; i = 1, ..., N, of the projects listed. Columns 1 through M describe the constraints of the organization. For any given project index, a project's value is calculated as

$$V = p_o \sum_{j \geqslant 1} p_j (1+W_j) D_j - C$$

in which

- $p_o$ = probability of successful completion
- $p_j$ = probability of implementation of application j
- $W_j$ = priority factor for application j
- $D_j$ = discounted net benefit for application j
- C = discounted cost of the project

The discounted net benefit of any given application can be expressed as

$$D = \sum_{t=1}^{T^1} z_t \left(\frac{1}{1+r}\right)^t$$

in which $z_t$ is the net benefit in the year t, $T^1$ is the last year in which benefits are generated from the application, and r is the rate used in the discount formula. In terms of project data $z_t$ is calculated in different ways, depending on the Benefit Documentation Case encountered. For Case One $z_t$ is calculated as the product of net unit benefit times volume in year t times percent affected in year t. In Case Two, $z_t$ is computed as the difference between added benefit and extra cost in year t. In Case Three, $z_t$ equals net benefit in year t as originally input.

The discounted research cost of the project (C) is

$$C = \sum_{t=1}^{T} c_t \left(\frac{1}{1+r}\right)^t$$

in which $c_t$ is the project's expenditure in year t, i.e., general expenditures plus new equipment expenditures, and T is the project's duration expressed in years.

A given constraint is specified by these three items: (1) The constraint coefficients $a_i$; i=1, ..., N; (2) the constraint inequality sign; and (3) the constraint bound b. The constraint bound is an upper bound when the inequality sign is "$\leqslant$" and a lower bound when the inequality sign is "$\geqslant$." The matrix columns display groups of constraints in this succession from left to right: (1) budget constraints; (2) limited resources constraints; (3) performance target constraints; and (4) added constraints.

For budget constraints, $a_i$ is the planned research expenditure on project i in a given year and b is the organization's budget in that year. $a_i$ is calculated by summing general research expenditures and new equipment expenditures for project i. The inequality sign is "$\leqslant$." For limited resources constraints, $a_i$ represents resource consumption by project i and b is the amount of resource available to the organization. The inequality sign is also "$\leqslant$." In the case of performance target constraints, $a_i$ measures the performance contribution of project i and b is the minimum performance standard for the organization as a whole. The inequality sign is "$\geqslant$." In the case of added constraints, the definition of $a_i$; i=1, ..., N, b and the inequality sign depends on the specific instance of constraint considered. For details on the specification of added constraints see Appendix B.

# INPUT AND GENERATED DATA REPORT

The information input as well as data generated by the program are printed in this order:

1. Project reports
2. Organization report
3. Summary tables.

## Project Reports

For each research project information package processed the various data items input are printed out under appropriate titles. The outcome is essentially a computer-produced replicate of the original project data sheet. In addition, the computed net benefit schedule for the project is printed. This output feature can be used in several ways, such as checking for coding or keypunching errors, producing updated reports on the status of research activities, and providing material for updating or cross-checking purposes.

## Organization Report

The organization report provides a summary of the number and types of constraints specified as feasibility criteria in the process of research program formulation. Constraints are numbered sequentially 1, 2, ..., etc. and for each number an explanatory title describes the nature of the constraint. The numbering of the constraints is consistent with the column number in the basic information matrix described in the chapter on *Matrix Generation.*

## Summary Tables

Three summary tables are produced. Table I displays a number of intermediate stages in the elaboration of the project benefits, i.e., column zero of the basic information matrix. Table I consists of eight columns of numbers:

1. *Project number* is a sequential number 1, 2, ..., etc., indicating the listing order.

2. *Project identification code number* is the code assigned to the project in Reference List 1.

3. *Gross benefit* is the aggregate present value of net[5] benefits from all the documented applications of a project.

4. *Research cost* is the present value of planned project expenditures.

5. *Net unadjusted benefit* is gross benefit minus research cost.

6. *U–factor* is an estimate of the degree of confidence that the economic results of a project as documented will materialize.

7. *EE–factor* is an estimate of the adjustment required to account for intangibles, or externalities not sufficiently considered in the documentation of the project.

8. *Adjusted net benefit* equals unadjusted net benefit multiplied by U–factor and EE–factor. Adjusted net benefit corresponds to the first column of the basic information matrix described in Matrix Generation.

Table II shows a ranking of the projects in terms of benefit over cost ratio. Benefit here is equivalent to adjusted net benefit. Benefit over cost ranking is useful for a quick assessment on the comparative potential performance of the projects. Projects with unusually high or low ratios can be identified easily. Unexpected discrepancies between benefits and costs in certain projects may also alert the investigator to double check the basic data and assumptions put forth in the documentation of these projects.

Table III lists numerical values and inequality indexes for all the constraints described in the organization report. Table III corresponds to the constraint columns, i.e., columns 1 through M of the basic information matrix described in the chapter on *Matrix Generation.*

# ZERO-ONE OPTIMIZATION

The zero-one integer programing method to select an optimum research program consists of identifying a mix of research projects whose sum of benefits is largest among all feasible alternatives. A research program is "feasible" if it is consistent with the organization's constraints. Several computer programs have been developed which identify an optimum project mix by means of a zero-one integer programing algorithm. These programs have been tested on a UNIVAC 1108 computer. The input required is the basic information matrix described in the chapter

[5]Net in this context means net with respect to extra production costs incurred in the application.

on *Matrix Generation.* The output generated includes: (1) Optimum research program; (2) total benefit associated with the optimum program; and (3) constraint levels corresponding to the optimum program.

In applied mathematics, the computational techniques used belong to the class of branch-and-bound integer programing algorithms. This class of algorithms is similar in structure to a tree-search algorithm because it must follow a path along the tree of solutions. Whether the node is terminal or not must be determined at each node of the tree. It is defined as "terminal" when all solutions having that node may be disregarded. This is the case only when all feasible solutions, if any—including the node—are worse off than the current best solution, i.e., the best solution found in prior search. When a terminal node is encountered the search backtracks to the immediately preceding node and embarks on a different path until another terminal node is found. The search is completed when the search process backtracks to the initial node of the tree, and such node is found to be terminal. In general the solution enumeration and record-keeping procedure implicit in this technique is common to most branch-and-bound types of zero-one programing algorithms. What distinguishes algorithms is the type and sequencing of terminality tests, i.e., tests used to determine whether or not a node is terminal.

In this sense these four programs represent different zero-one integer programing algorithms: (1) Petersen algorithm; (2) revised Petersen algorithm; (3) GR algorithm; and (4) zero-one algorithm with bounded linear programing subroutine. The comparative performance of algorithms 1, 2, and 3, measured in execution time, varied according to the data used in the test runs. Although the Petersen[6] algorithm requires more iterations to identify an optimum set than do algorithms 2 and 3, its computing time per iteration is less. The revised Petersen algorithm and the GR algorithm perform best when (a) the number of constraints is large in relation to the number of projects or (b) the constraints are tight and as a consequence, there are relative fewer feasible solutions to the optimum project mix problem. Algorithm 4 represents an attempt to implement a computational technique proposed by Geoffrion.[7] The attempt was only partially successful in that an operational program was developed, but further programing work is required to achieve fully the potential efficiency of the technique.

## ANALYSIS REPORTS USING OPTIMIZATION

Sensitivity analysis based on an optimization scheme addresses itself to the question of how an optimum solution varies in response to changes in the problem data. In the context of research program formulation and evaluation, sensitivity analysis can be used to explore organization bottlenecks and robustness of optimum decisions.

Bottlenecks in an organization can be investigated by modifying the specification of the organization's constraints. This can be done by adding or deleting constraints as well as by relaxing or strengthening constraints. Comparing optimum sets of projects obtained under different constraint specifications demonstrates the effect of changes in the constraints. At the same time constraint sensitivity-analysis provides an indication of the potential effectiveness of management policies which can be interpreted as changes in the organization's constraints. For instance, one may explore in a simulated experiment the effects of expanding future budgets by 10 percent on a research program.

Robustness of optimum decisions concerns the question of how much errors in data affect the computation of optimum project sets. Since subjective judgments and guess work are used in determining a portion of the basic data pertaining to research evaluation and planning, the question is legitimate in this context. An optimum solution is said to be "robust" if it is not drastically affected by error variability in the estimates making up the data base. Robustness determinations can be made in two ways; (1) given a specific change in the optimum solution determine the variation in the data required to produce it; and (2) given a change in the data, determine the induced variation on the optimum set.

Sensitivity analysis in the context of zero-one optimization is performed by the program ZERONE

[6]Petersen, Clifford C. *Computational experience with variants of the Balas algorithm applied to the selection of R. and D. projects.* Manage. Sci. 13(9): 736-750. 1967.

[7]Geoffrion, A. M. *Implicit enumeration using an imbedded linear program.* RAND Corp. RM-5406-PR. 13 p. 1967.

and its complementary subprograms. Standard options are provided for these types of analysis:

A: Add, delete. or change an activity or a constraint.

B: In some specified constraints, change constraint bounds by a fixed additive or multiplicative amount.

C: For all projects listed, determine the amount of error in the estimate of the project benefit necessary to alter the optimum solution with respect to that project.

In ZERONE any sequence of sensitivity analyses can be carried out. The data deck is set up as follows:

1. Control cards
2. Basic tableau cards
3. Sensitivity analysis cards.

The control cards specify the dimensions of the basic tableau as well as the number and sequence of sensitivity analysis options desired. The basic tableau is similar to the basic information matrix described in the chapter on *Matrix Generation.* It includes project benefits, constraint coefficients, constraint inequality signs, and constraint bounds. Sensitivity analysis cards are required only for options in Type A and Type B. Specific operating instructions for ZERONE are given in Appendix C.

## SUMMARY

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*Oxford:* 945.4:U65.012–U681.142.
*Retrieval Terms:* research administration; proposal evaluation; analytical procedures; computer programs; mathematical models.

Evaluating and planning research in an organization usually requires considerable detailed information. The data needed are concerned with the organization and its objectives and resources and, for each research proposal, the expected contributions to these aims and the requirements for resources.

To detail these information requirements, a data classification scheme was developed. From the scheme, a mechanism for collecting, processing, and analyzing data was devised.

This report provides instructions on how to complete the data collection forms, code the data for transfer to punchcards, and process the data by computer programs. It complements the publication *An Analytical Procedure to Assist Decision-Making in a Government Research Organization* (USDA Forest Service Research Paper PSW-80).

The set of standardized data collection forms include three reference lists, and project data sheets. Reference list one classifies and identifies the research proposals to be examined; reference list two itemizes the organization's resources; and reference list three enumerates the organization's objectives. The project data sheets serve the purpose of collecting information on individual research proposals.

A coding system transfers the information from the data collecting forms to punchcards. This work involves essentially (a) the card deck layout, i.e., the sequence order of cards in the deck; (b) the information content of each card; and (c) the keypunch configuration for every item on a given card.

A set of computer programs is used to process the information stored on cards. Written in FORTRAN V language, the programs are operational on a UNIVAC 1108 computer. The major tasks that can be performed by these programs are: (a) preliminary elaboration of data, such as calculation of sums, percentages, discounted values, and benefit-cost ratios; (b) tabular display of data as originally entered as well as in elaborated form; (c) computation of best research activity mix under current organizational constraints; (d) computation of best project mix under alternative conditions, i.e., sensitivity analysis. The computations of (c) and (d) are centered around a zero-one integer programing optimization scheme

# APPENDIXES

## A—Examples of Data Collection

**Reference List 1**

| | *Code number* |
|---|---|
| Project description: | |
| Polysulphide process | 101 |
| Better design in paper production | 102 |
| Dry forming | 103 |
| Quality of paper products | 104 |
| Cost of paper | 105 |
| Drying process for oak | 201 |
| Pit aspiration in coniferous sapwood | 202 |
| Moisture content prediction | 203 |
| Eliminate coloring defects | 204 |
| Check prevention method | 205 |
| Protection of chips in outdoor storage | 301 |
| Chemical properties of wood | 302 |
| Conversion of wood residues | 303 |
| Pollution reduction | 304 |
| Tall oil | 305 |
| Strength properties of wood elements | 401 |
| Interaction of wood elements | 402 |
| Techniques for use of wood in housing | 403 |
| Particle board, fiberboard design | 404 |
| Acoustical performance of wood housing | 405 |
| Wood defect detection | 501 |
| Wood species identification | 502 |
| Nutrient modification | 503 |
| Lumber grade mix | 504 |
| Sawing methods | 505 |

**Reference List 2**

| | *Code number* | *Unit of measure* |
|---|---|---|
| Resource description: | | |
| Lignin chemists | 001 | Man years |
| Wood engineers | 002 | Man years |
| Systems analysts | 003 | Man years |
| Electronic microscope Type A | 004 | Hrs. per week |
| Electronic microscope Type B | 005 | Hrs. per week |
| Computer Type X-next year | 006 | Hrs. per week |
| Pilot plant space | 007 | Hrs. per week |
| Laboratory space-next year | 008 | Sq. ft. |
| Laboratory space-two years from now | 009 | Sq. ft. |
| Office space | 010 | Rooms |

**Reference List 3**

| | *Code number* | *Unit of measure* |
|---|---|---|
| Criterion description: | | |
| Increase employment | 001 | Percentage points |
| Increase proportion of people above poverty level | 002 | Percentage points |
| Reduce wood waste in cutting | 003 | Million B.F. |
| Reduce sulphur pollution near paper plants | 004 | Percentage points |
| Reduce wood waste in processing | 005 | Million B.F. |
| Increase amount of wood products recycled-three years from now | 006 | Million cu. ft. |
| Same-five years from now | 007 | Million cu. ft. |
| Same-ten years from now | 008 | Million cu. ft. |

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - Section 1: Identification

1.1 Number and Title 101 POLYSULPHIDE PROCESS

1.2 Research Leader X, ALPHA

1.3 Expected Research Output New Chemical Pulping Process

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - Section 2: Resource Outlays

2.1 Expenditures Table ($ Thousands)

| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| General Exp. | 80 | 80 | 80 | 80 | 80 | 80 | 120 | 80 | 80 | 80 |
| New Equip. | | | | | | 1250 | 500 | 250 | 250 | 250 |

2.2 Other Resource Outlays Table

| Res. Number | 1 | 7 |
|---|---|---|
| Amount | 25 | 1000 |

2.3 Probability of successful completion 50%

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - Section 3: Utility Contributions

3.1 Application Number and Title 1 Reduce Raw Material Requirements

3.2 Benefit per unit $6.25 Extra-cost per unit $6.00

3.3 Industrial Implementation Schedule (units = Cords)

| Year | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|
| Volume | 10 mill. | 10 mill. | 10 mill. | 10 mill. | 10 mill. |
| Percent | 10 | 25 | 40 | 50 | 60 |

3.4 Benefit Accrual Schedule

| Year | | | | | |
|---|---|---|---|---|---|
| Added benefit | | | | | |
| Extra cost | | | | | |

3.5 Other Performance Measures Table

| Crit. Number | 3 |
|---|---|
| Value | .5 |

3.6 Adjustment fraction —20%[1]

3.7 Probability of successful implementation 50%

3.8 References and comments

[1] Low public priority

Documentation of Project 101

- - - - - - - - - - - - - - - - - - - - - - - - - - - - Section 1: Identification

1.1 Number and Title 403 WOOD HOUSING DESIGN

1.2 Research Leader Z. GAMMA

1.3 Expected Research Output More economic design

- - - - - - - - - - - - - - - - - - - - - - - - - - - - Section 2: Resource Outlays

2.1 Expenditures Table ($ Thousands)

| Year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| General Exp. | 120 | 160 | 200 | 200 | 160 | 160 | 160 | 120 |
| New Equip. | | | | | | | | |

2.2 Other Resource Outlays Table

| Res. Number | 2 |
|---|---|
| Amount | 15 |

2.3 Probability of successful completion 75%

- - - - - - - - - - - - - - - - - - - - - - - - - - - - Section 3: Utility Contributions

3.1 Application Number and Title Reduce cost of wooden housing through improved design

3.2 Benefit per unit $500 Extra-cost per unit

3.3 Industrial Implementation Schedule (units = houses)

| Year | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|
| Volume | 1250 Thou. each year | | | | | |
| Percent | 5 | 5 | 5 | 5 | 5 | 5 |

3.4 Benefit Accrual Schedule

| Year | |
|---|---|
| Added benefit | |
| Extra cost | |

3.5 Other Performance Measures Table

| Crit. Number | 1 | 3 | 5 |
|---|---|---|---|
| Value | $10^{-3}$ | 5 | 1 |

3.6 Adjustment fraction 15%[1]

3.7 Probability of successful implementation 50%

3.8 References and comments

[1] High priority project

Documentation of Project 301

- - - - - - - - - - - - - - - - - - - - - - - - - - - - Section 1: Identification

1.1 Number and Title 301 PROTECTION OF OUTDOOR STORAGE CHIPS

1.2 Research Leader Y BETA

1.3 Expected Research Output New Chemical Treatment for Chips in Outdoor Storage

- - - - - - - - - - - - - - - - - - - - - - - - - - - - Section 2: Resource Outlays

2.1 Expenditures Table ($ Thousands)

| Year | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| General Exp. | 145 | 145 | 145 | 155 | 105 |
| New Equip. | | | | | |

2.2 Other Resource Outlays Table

| Res. Number | 1 |
|---|---|
| Amount | 10 |

2.3 Probability of successful completion 50%

- - - - - - - - - - - - - - - - - - - - - - - - - - - - Section 3: Utility Contributions

3.1 Application Number and Title 1 Decrease storage loss of chips

3.2 Benefit per unit $3.00 Extra-cost per unit $2.67

3.3 Industrial Implementation Schedule (units = tons)

| Year | 4 | 5 | 6 | 7 | 8 | 9 | 10 | . . . . . | 15 |
|---|---|---|---|---|---|---|---|---|---|
| Volume | 3 mill. each year | | | | | | | . . . . . | - |
| Percent | 5 | 10 | 25 | 50 | 50 | 50 | 50 | - - - - - - | 50 |

3.4 Benefit Accrual Schedule

| Year | |
|---|---|
| Added benefit | |
| Extra cost | |

3.5 Other Performance Measures Table

| Crit. Number | 1 | 3 |
|---|---|---|
| Value | $10^{-5}$ | .5 |

3.6 Adjustment fraction 0%

3.7 Probability of successful implementation 75%

3.8 References and comments

Documentation of Project 403

# B—Operating Instructions for Program FILE

## A. General Instructions

Coding instructions in Sections B, C, and D that follow assign a field to each data item entered on a card. A "field" is a set of adjacent columns; for example, columns 1-6 form a six-column field. Except for titles, which can be entered in free format onto the preassigned field, coded data must be "right-oriented" or "right-justified." This requirement means that any input item is placed in its field in such a way that its right most digit or letter falls into the right most column of the field. For example, the number "521" would be input into columns 43-48 as follows: columns 43-45 empty, "5" into column 46, "2" into column 47 and "1" into column 48.

In all cards, columns 69-80 are reserved for card identification codes:

1. Data package code number: columns 69-72
2. Card type code word: columns 73-76
3. Continuation card number: columns 77-80.

The data package code is "0"—or blank—for control cards and organization data cards. It corresponds to the project identification code number for project data cards. Card type code words are listed below in B, C, and D. Continuation card numbers are used to identify continuation cards that follow a given card. "1" identifies the first continuation card, "2" the second, etc.

Sets of information items can be entered onto data cards in two different "patterns": (1) A-pattern or array pattern; or (2) S-pattern or scatter pattern.

A-pattern is used to input arrays of numbers. The first 10 numbers of the array are entered into columns 1-60, one six-column field for each number. If the array contains more than 10 numbers, continuation cards are used, in the same fashion, to input the remaining numbers, one continuation card for every additional 10 numbers. Columns 61-66 can be used, if necessary, to enter a scale factor. This factor expresses the power of 10 by which the entries in columns 1-60 of the same card must be multiplied for scaling purposes. Numbers must be entered onto card(s) in the same order as they appear in the array.

The S-pattern is used to enter heterogeneous numerical items as well as titles. The order of entry is specified in the following instructions. Unless otherwise indicated, entries are assigned six-column fields—starting with columns 1-6.

## B. Instructions for Control Cards

| *Card*[1] *sequence* | *Coding*[2] *pattern* | *Entries* | *Card*[3] *type* |
|---|---|---|---|
| 1 | S | a. Number of budget constraints<br>b. Number of resource constraints<br>c. Number of performance constraints | CCC |
| 2 | A | Budget constraint years, as many as indicated in 1.a. If none omit card. | YYY |
| 3 | A | Resource code numbers, as many as indicated in 1.b. If none omit card. | RRR |
| 4 | A | Performance criteria numbers, as many as stated in 1.c. If none omit card. | TTT |

[1]See text: *Data Formatting—Control Cards.*

[2]See *A. General Instructions.*

[3]Card type code word.

## C. Instructions for Project Data Cards

| *Card*[1] *sequence* | *Coding*[2] *pattern* | *Entries* | *Card*[3] *type* |
|---|---|---|---|
| 1 | S | a. Project code number<br>b. Descriptive title: cols. 7-68 | IDF |
| 2 | S | a. Duration of project in years<br>b. Probability of completion—DS 2.3[4]<br>c. New equipment expenditures? "1" if yes. Blank if none.<br>d. Number of limited resources used. Blank if none.<br>e. Number of applications. Blank if only one. | PAR |
| 3 | A | General expenditures ($1,000)—second row of DS 2.1 | GEN |
| 4 | A | New equipment expenditures—third row of DS 2.1. Omit if 2.c is blank. | EQP |
| 5 | A | Resource code numbers—first row of DS 2.2. Omit if 2.d is blank. | OLR |
| 6 | A | Amounts used —second row of DS 2.2. Omit if 2.d is blank. | USE |
| 7 | S | Descriptive title of the application: cols. 1-68 | APP |

| *Card*[1] *sequence* | *Coding*[2] *pattern* | *Entries* | *Card*[3] *type* |
|---|---|---|---|
| 8 | S | a. First year in which benefits will be realized<br>b. Last year in which benefits will accrue<br>c. Chances of implementation–DS 3.7<br>d. Adjustment fraction–DS 3.6<br>e. Benefit Documentation Case. Blank if Case Three.<br>f. Other performance contributions number. Blank if none. | APR |
| 9 | S | a. Benefit per unit ($)<br>b. Extra cost per unit ($) Blank, if a. entry is net unit benefit. For a. and b. see DS 3.2.<br>c. Scale factor to adjust a. and b. Power of 10.<br>d. Unit of production to which a. and b. refer, in words, cols. 19-68.<br>Omit this card unless 8.e is "1" | UNB |
| 10 | A | Production volumes, i.e., second row of DS 3.3, if 8.e is "1"; or | VOL |
| | A | Added benefits, i.e., second row of DS 3.4, if 8.e is "2"; or | BEN |
| | | Net benefits, i.e., second row of DS 3.4, if 8.e is blank. | NET |
| 11 | A | Percent affected, i.e., third row of DS 3.3, if 8.e is "1" or | PCT |
| | A | Extra cost, i.e., third row of DS 3.4, if 8.e is "2." Omit if 8.e is blank. | ECO |
| 12 | A | Performance criterion code numbers–first row of DS 3.5. Omit if 8.f is blank. | CRT |
| 13 | A | Performance measures–second row of DS 3.5. Omit if 8.f is blank. | PRF |

[1] See text: *Data Formatting–Project Data cards.*

[2] See *A. General Instructions.*

[3] Card type code word.

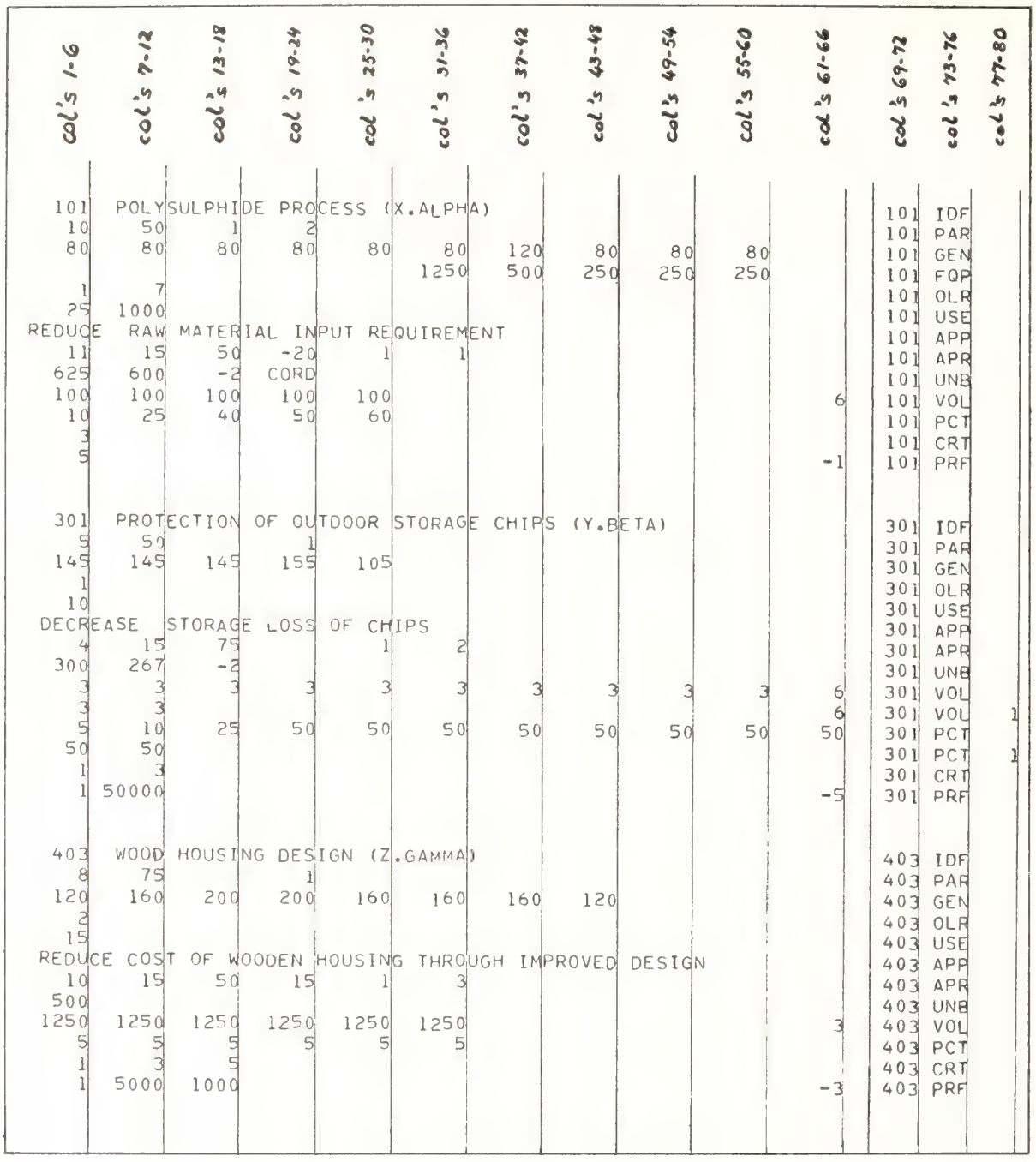
[4] DS 2.3 stands for data sheet, item 2.3.

How the information on the three project data sheets is transferred onto data cards is illustrated in the printout on the following page. Each row displayed represents a card image, i.e., an 80-column field.

## D. Instructions for Organization Data Cards

| *Card*[1] *sequence* | *Coding*[2] *pattern* | *Entries* | *Card*[3] *type* |
|---|---|---|---|
| 1 | A | Budget levels for years specified in Control Card 2. Omit if entry a. in Control Card 1. is blank. | BUD |
| 2 | A | Availability levels for resources specified in Control Card 3. Omit if entry b. in Control Card 1. is blank. | RES |
| 3 | A | Performance level for criteria specified in Control Card 4. Omit if entry c. in Control Card 1. is blank. | REQ |
| A.1 | S | a. Number of projects subject to allocation constraints<br>b. Minimum funding level. Blank if not specified.<br>c. Maximum funding level. Blank if not specified<br>d. Blank if funding limits are expressed as percentages of the total research budget. "1" if the actual amounts are stated. Cols. 19-20.<br>e. Scale factor–power of 10: cols. 21-22<br>f. Budget year order number. Blank if first budget year: cols. 23-24.<br>g. Name of the functional or administrative unit affected by the allocation constraint: cols. 25-68 | BAL |
| A.2 | A | Project code numbers. If only a fraction of the project is affected, enter the percentage in front of the code number, e.g., "10 percent of project 19" is coded as "10019." | BAL |
| I.1 | S | a. Number of projects involved in the interdependence relation<br>b. Inequality code:<br>"0" if ⩾<br>"1" if ⩽<br>"2" if =<br>c. Constraint bound<br>d. Descriptive title in cols. 25-68 | DEP |
| I.2 | A | Project code numbers. If the constraint coefficient correspondent to the project is different from one, | |

*Continued*



| col's 1-6 | col's 7-12 | col's 13-18 | col's 19-24 | col's 25-30 | col's 31-36 | col's 37-42 | col's 43-48 | col's 49-54 | col's 55-60 | col's 61-66 | col's 69-72 | col's 73-76 | col's 77-80 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 101 | POLYSULPHIDE PROCESS (X.ALPHA) | | | | | | | | | | 101 | IDF | |
| 10 | 50 | 1 | 2 | | | | | | | | 101 | PAR | |
| 80 | 80 | 80 | 80 | 80 | 80 | 120 | 80 | 80 | 80 | | 101 | GEN | |
| | | | | | 1250 | 500 | 250 | 250 | 250 | | 101 | FOP | |
| 1 | 7 | | | | | | | | | | 101 | OLR | |
| 25 | 1000 | | | | | | | | | | 101 | USE | |
| REDUCE | RAW MATERIAL INPUT REQUIREMENT | | | | | | | | | | 101 | APP | |
| 11 | 15 | 50 | -20 | 1 | 1 | | | | | | 101 | APR | |
| 625 | 600 | -2 | CORD | | | | | | | | 101 | UNB | |
| 100 | 100 | 100 | 100 | 100 | | | | | | 6 | 101 | VOL | |
| 10 | 25 | 40 | 50 | 60 | | | | | | | 101 | PCT | |
| 3 | | | | | | | | | | | 101 | CRT | |
| 5 | | | | | | | | | | -1 | 101 | PRF | |
| 301 | PROTECTION OF OUTDOOR STORAGE CHIPS (Y.BETA) | | | | | | | | | | 301 | IDF | |
| 5 | 50 | | 1 | | | | | | | | 301 | PAR | |
| 145 | 145 | 145 | 155 | 105 | | | | | | | 301 | GEN | |
| 1 | | | | | | | | | | | 301 | OLR | |
| 10 | | | | | | | | | | | 301 | USE | |
| DECREASE | STORAGE LOSS OF CHIPS | | | | | | | | | | 301 | APP | |
| 4 | 15 | 75 | | 1 | 2 | | | | | | 301 | APR | |
| 300 | 267 | -2 | | | | | | | | | 301 | UNB | |
| 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 6 | 301 | VOL | |
| 3 | 3 | | | | | | | | | 6 | 301 | VOL | 1 |
| 5 | 10 | 25 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 301 | PCT | |
| 50 | 50 | | | | | | | | | | 301 | PCT | 1 |
| 1 | 3 | | | | | | | | | | 301 | CRT | |
| 1 | 50000 | | | | | | | | | -5 | 301 | PRF | |
| 403 | WOOD HOUSING DESIGN (Z.GAMMA) | | | | | | | | | | 403 | IDF | |
| 8 | 75 | | 1 | | | | | | | | 403 | PAR | |
| 120 | 160 | 200 | 200 | 160 | 160 | 160 | 120 | | | | 403 | GEN | |
| 2 | | | | | | | | | | | 403 | OLR | |
| 15 | | | | | | | | | | | 403 | USE | |
| REDUCE | COST OF WOODEN HOUSING THROUGH IMPROVED DESIGN | | | | | | | | | | 403 | APP | |
| 10 | 15 | 50 | 15 | 1 | 3 | | | | | | 403 | APR | |
| 500 | | | | | | | | | | | 403 | UNB | |
| 1250 | 1250 | 1250 | 1250 | 1250 | 1250 | | | | | 3 | 403 | VOL | |
| 5 | 5 | 5 | 5 | 5 | 5 | | | | | | 403 | PCT | |
| 1 | 3 | 5 | | | | | | | | | 403 | CRT | |
| 1 | 5000 | 1000 | | | | | | | | -3 | 403 | PRF | |

**Printout**

| Card[1] sequence | Coding[2] pattern | Entries | Card[3] type |
|---|---|---|---|
| | | enter its value in front of the project code number, e.g., if the coefficient value for project 4 is "-3," the correct code is "-3004" | DEP |
| M.1 | S | a. Number of projects whose coefficients are different from zero.<br>b. Inequality code (See I.1.b)<br>c. Constraint bound<br>d. Scale factor–power of 10–to adjust entry c.<br>e. Descriptive title: cols. 25-68 | MSC |
| M.2 | A | Code numbers of projects whose coefficients in the constraint specified are different from zero | MSC |
| M.3 | A | Coefficient values correspondent to projects listed in M.2 | VAL |

[1]See text: *Data Formatting–Organization Data Cards.*

[2]See *A. General Instructions.*

[3]Card type code word.

# C–Operating Instructions for Program ZERONE

## Control Cards

At most only two control cards are needed: CC1 and CC2.

The entries in card CC1 are:

1. Number of projects, i.e., rows of the basic tableau: cols. 1-4.
2. Number of constraints, i.e., columns of the basic tableau, except for column 0: cols. 5-8.
3. Number of sensitivity analysis options desired. Blank if none: cols. 9-12.

The entries in card CC2 are:

Column 1: First sensitivity analysis option (A, B, or C) wanted.

Column 2: Second sensitivity analysis option (A, B, or C) wanted, etc.

Card CC2 is omitted if entry 3 in card CC1 is blank.

## Basic Tableau Cards

The basic tableau cards input the basic information matrix produced by program FILE (see chapter on *Matrix Generation*). For details on the card formats consult the eight FORTRAN V statements following the statement "10 CONTINUE" in the listing of program ZERONE. Note that

| | |
|---|---|
| MV | : number of projects |
| NC | : number of constraints |
| AZERO(I), I=1, MV | : project benefits |
| A(I,J), I=1, MV; J=1, NC | : constraint coefficients |
| JQ(J), J=1, NC | : inequality indexed<br>"0" for $\geqslant$<br>"1" for $\leqslant$<br>"2" for = |
| B(J), J=1, NC | : constraint bounds |

## Sensitivity Analysis Cards

For each option Type A specified in control card CC2, two sensitivity analysis cards are required: SA1 and SA2. The entries in card SA1 are:

1. Columns 4-6: blank if a constraint column of the basic tableau is modified (add, change or delete): "ACT" if a row of the basic tableau is modified.
2. Columns 7-12: number of constraint coefficients modified.
3. Columns 13-18: new inequality sign when a constraint inequality is changed, blank otherwise.
4. Columns 19-24: new constraint bound in the modified row (column).
5. Columns 25-30: scale factor–power of 10–to adjust entry 4. Blank if not needed.
6. Columns 31-36: modification required, i.e.,
   Blank if add one column (row)
   "1" if delete one column (row)
   "2" if change one column (row).
7. Columns 37-42: column (row) number of array deleted or changed, blank otherwise.
8. Columns 45-80: explanatory title.

Card SA2 is omitted if entry 6 in card SA1 is equal to "1." The entries in card SA2 are the values of the non-zero coefficients of the modified column (row), together with their row (column) indexes. Eight-column fields are used to input such entries, the coefficient value in the first five columns and the coefficient index in the remaining three. Only 10 such composite entries can be fit into a card.

Consequently, more than one card is required if more than 10 are entered.

For each option Type B specified in control card CC2, one sensitivity analysis card (SB) is input. The entries in card SB are:

1. Columns 1-6: first constraint number in the sequence of constraints modified.
2. Columns 6-12: last constraint number in the sequence.
3. Columns 13-18: number of fixed increments desired in the constraint bounds.
4. Columns 19-24: additive or multiplicative increment at each step.
5. Columns 25-30: scale factor—power of 10—to adjust entry 4.
6. Columns 31-36: blank if entry 4 specified an additive increment, "1" if entry 4 specifies a multiplicative increment.
7. Columns 34-42: number of backward increments required to adjust the magnitude of the constraint bounds after the last step is completed.
8. Columns 45-80: explanatory title.

No sensitivity analysis card is required for option Type C. As an example, suppose that card CC2 specified the option sequence CABCA. Then, the sensitivity analysis cards would be arranged in this sequence:

1. SA1
2. SA2
3. SB
4. SA1
5. SA2

And the ZERONE program would operate as follows:

1. Finds the optimum project mix on the basis of the original basic tableau data.
2. Looks at the first project in the list and looks up the original solution. If the project appears in the solution an exclusion constraint is imposed on the project, i.e., "the project must stay out." If the project does not appear in the solution an inclusion constraint is imposed on the project, namely, "the project must stay in." A new solution is found on the basis of the original data plus the additional constraint. The same process is repeated for each project in the list.
3. Modifies the original basic tableau according to the instructions contained in cards 1 and 2 and finds an optimum mix on the basis of the modified data.
4. Some constraint bounds are adjusted by a fixed increment according to the instructions in card 3. Entries 1 and 2 specify which constraints. Entries 4, 5, 6 specify the magnitude and type of the increment. The optimum project mix is found. These operations are repeated for as many steps as specified in entry 3. Before proceeding to the next sensitivity analysis the constraint bounds are readjusted as indicated in entry 7 of card 3.
5. Repeats operations specified under 2 above only this time starting from the basic tableau as modified through 3 and 4.
6. Modifies basic tableau according to instructions in cards 4 and 5 and then finds corresponding optimum solution.

Rensi, Giuseppe, and H. Dean Claxton.

1972. **A data collection and processing procedure for evaluating a research program.** Berkeley, Calif., Pac. Southwest Forest and Range Exp. Stn. 18 p. (USDA Forest Serv. Res. Paper PSW-81)

A set of computer programs compiled for the information processing requirements of a model for evaluating research proposals are described. The programs serve to assemble and store information, periodically update it, and convert it to a form usable for decision-making. Guides for collecting and coding data are explained. The data-processing options available and instructions on operation of the software are outlined.

*Oxford:* 945.4:U65.012–U681.142.
*Retrieval Terms:* research administration; proposal evaluation; analytical procedures; computer programs; mathematical models.

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Rensi, Giuseppe, and H. Dean Claxton.

1972. **A data collection and processing procedure for evaluating a research program.** Berkeley, Calif., Pac. Southwest Forest and Range Exp. Stn. 18 p. (USDA Forest Serv. Res. Paper PSW-81)

A set of computer programs compiled for the information processing requirements of a model for evaluating research proposals are described. The programs serve to assemble and store information, periodically update it, and convert it to a form usable for decision-making. Guides for collecting and coding data are explained. The data-processing options available and instructions on operation of the software are outlined.

*Oxford:* 945.4:U65.012–U681.142.
*Retrieval Terms:* research administration; proposal evaluation; analytical procedures; computer programs; mathematical models.

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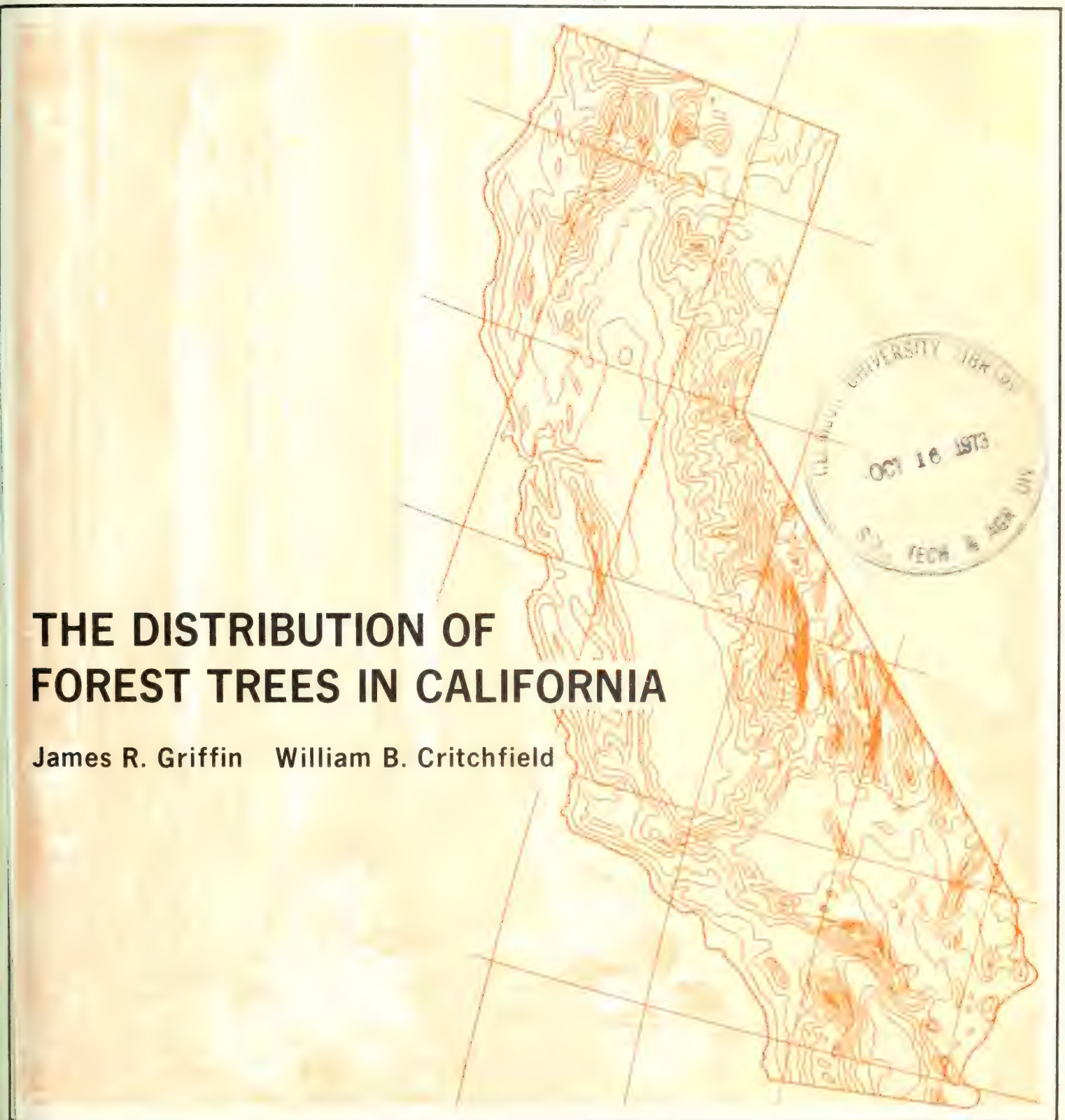

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# THE DISTRIBUTION OF FOREST TREES IN CALIFORNIA

James R. Griffin  William B. Critchfield

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## The Authors

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California's natural vegetation, reflecting the climatic and topographic diversity of the State, includes a varied assortment of tree species. Some of them cover millions of acres; others are so rare that every individual could easily be counted. Twenty-one species grow naturally only within the State. Trees dominate the vegetation on more than a third of the land area of California. Because of their dominant ecological role and the economic importance of some species as wood-producers, a wealth of information has accumulated on tree distribution. Some of this information has been published in scattered sources, often in the form of small-scale distribution maps, but much of it is unpublished. Although data for "definitive" maps of some species are still lacking, enough distributional information is available to assemble this preliminary atlas.

Natural distributions of 86 forest and woodland species are mapped here. The choice of species to be included or excluded was dictated partly by the coverage of our principal source of information: the Vegetation Type Map (VTM) survey of California. Tree-like willows *(Salix* sp.*)* were not identified to species by VTM crews, and this genus is not included. Desert areas were excluded from VTM coverage, so we have also omitted desert wash and oasis species for lack of data.

With these limitations, we have included as many traditional "trees" as possible. Species which are shrubby over most of their range, and tree-like only in favorable spots, are omitted. Some species in genera such as *Acer, Ceanothus, Prunus,* and *Rhamnus* are in this category.

Some woody plants have commonly occurring tree and shrub forms, and the total range of these species is shown on the maps. This situation is common in the oak family. The *Quercus garryana* map, for example, includes the ranges of the shrubby varieties *breweri* and *semota* as well as that of the typical tree. The original VTM data often distinguished between the tree and shrub forms of a species, but there is no practical way to show this kind of detail at the scale of these maps.

Geographic coverage of this atlas is limited to California and that part of Nevada adjacent to Lake Tahoe. This corner of Nevada is floristically related to California, and was included in the VTM survey. On a few maps, isolated stands in other parts of western Arizona, western Nevada, and southern Oregon are shown when they are of special significance to California distribution patterns.

The distribution of all species is shown at the same scale. For species with restricted ranges, we have included map inserts at larger scales to show greater detail. Most of the map inserts are adapted from the U.S. Geological Survey 1:500,000-scale map of California.

The maps are supplemented by descriptive notes on genera and species. The species notes cover pertinent data that cannot be shown on a map, including elevational limits, geographical relationships of species, natural hybridization and intergradation between species, and the ecological role of the species in the plant communities of which it is a component. Historical notes are included, particularly for rare or endemic species. The principal published and unpublished sources of information used to supplement VTM and other Forest Service data are summarized by species. In some cases, the references cited add little to unpublished distribution data, but we have included them because they provide other kinds of information on the species and its ecological context.

Scientific names follow the usage in Little (1953) except for a few instances in which Munz (1959, 1968) and other California authorities usually differ. Common names from Little (1953) are supplemented by names of widespread usage in California.

The major physiographic features of California are illustrated and labeled in *figures 1* and *2*, and county names are shown in *fig.3*. Some local place names are shown on the inset maps. The locations of most other place names mentioned in the text are listed to the nearest half-minute of latitude and longitude in *Geographic Location of Place Names*. The coordinates designate a central point of linear features (rivers and streams) and areal features (mountain ranges and valleys). We have excluded only larger towns and cities, which can readily be located in a standard atlas or on a road map of California. Local place names sometimes provided useful clues to tree distribution; the many names incorporating "quaking aspen" in the northeastern part of the State nearly always indicate an isolated grove of *Populus tremuloides*, and throughout the length of the Sierra Nevada "tamarack" place names refer to *Pinus contorta.*

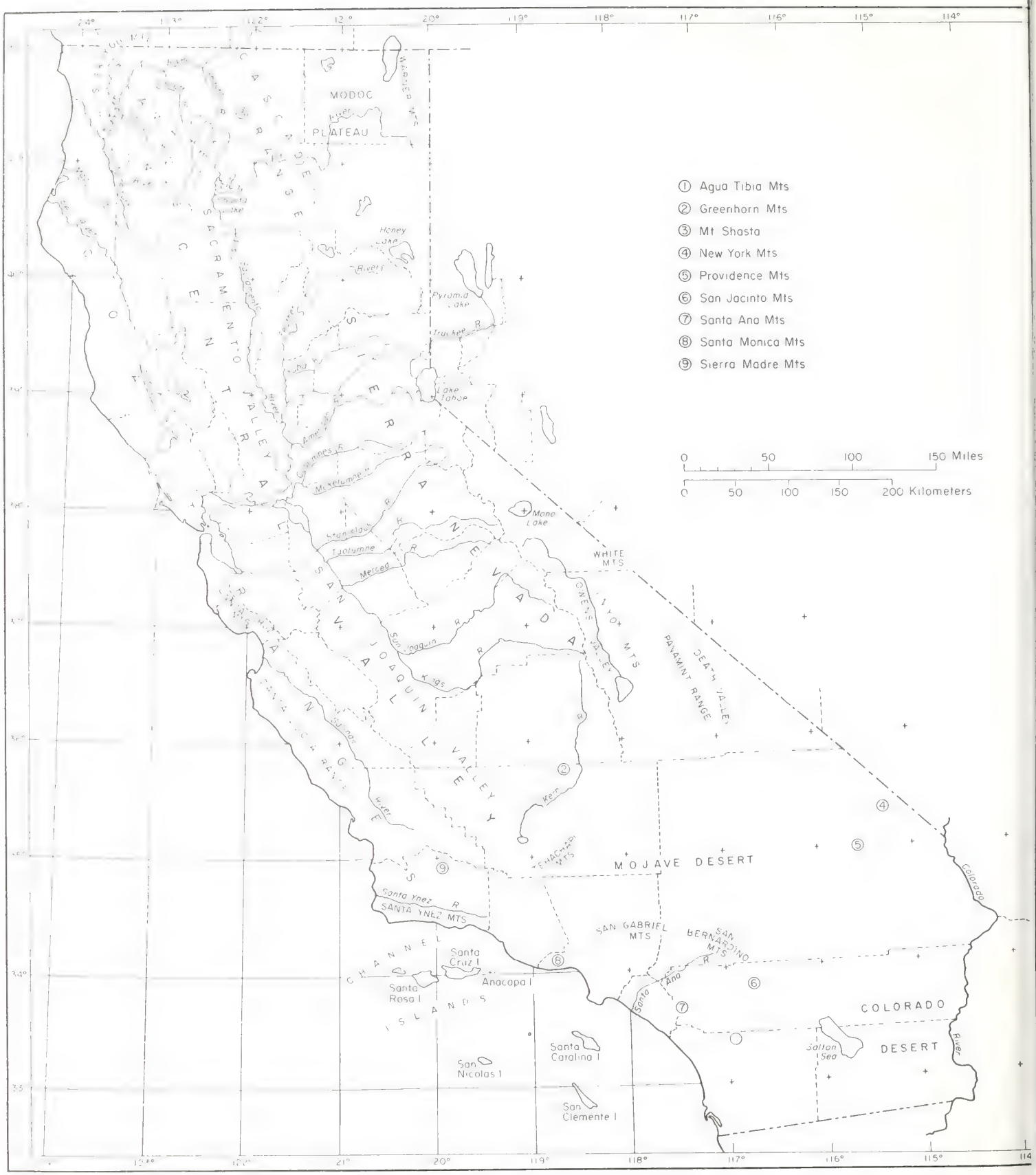


**Figure 1**—Names of important physiographic features of California.

**Figure 2**—Relief map of California (prepared by U.S. Geological Survey).

# SOURCES OF INFORMATION

Our major sources of distribution data were the maps, notes, plot records, and herbarium specimens of the VTM survey. Between 1928 and 1940, VTM field crews, under the direction of Albert E. Wieslander, mapped almost half of California's vegetation. Mapping was concentrated in the south Coast Ranges, southern California, and the central Sierra Nevada *(fig. 3)*. Preliminary work was started in scattered parts of the north Coast Ranges. Special surveys mapped the vegetation of Lassen, Sequoia, and Yosemite National Parks.

Early prospects of the VTM survey were outlined by Wieslander (1935). Jensen (1939) summarized progress in the Santa Cruz Mountains. Wilson (1941) reported on work in the Lake Tahoe region of western Nevada. Field work finally covered 40 million acres, but the full results of the project were never summarized. Colored vegetation type maps were published between 1932 and 1943 for 23 15- and 30-minute quadrangles, mostly in southern California but including a few in other parts of the State. Most of the remaining sheets were issued as generalized blue-line prints (Pacific Southwest Forest and Range Exp. Stn. 1963b). However, the original field type maps, a separate series of maps showing scattered occurrences of trees, and the associated notes and photographs contain an abundance of unpublished tree distribution data. We also referred to the 25,000 herbarium specimens collected by the VTM field crews, now in the Herbarium of the University of California at Berkeley. The initial motivation for this publication was the desire to condense all of these scattered VTM sources into one set of conveniently available species distribution maps.

Another important source of information was the State Cooperative Soil-Vegetation (SV) survey (Pacific Southwest Forest and Range Exp. Stn. 1963a). In 1947 the SV survey replaced the VTM survey as the major vegetation mapping project in California (California Forest and Range Exp. Stn. 1958). The SV survey has worked mainly in privately owned areas not covered by the VTM crews *(fig. 3)*. Most of the SV survey's tree data appear as species symbols on 7.5-minute maps. Legends for the more recent SV maps—for example, the Shasta County quadrangles—also contain supplementary notes on tree ranges (Mallory et al. 1965). We compiled distributions directly from the published sheets. Preliminary copies of unpublished SV sheets were also consulted.

Other Forest Service data came from Forest Survey plots, forest insect and disease survey plots, correspondence with personnel of the National Forests, and special items, such as an old forest type map for the Shasta National Forest.

Several partial compilations of individual species distributions have been made from these sources at different times. Some southern California VTM data were summarized on large-scale linen maps. Later, range maps for many species were compiled from VTM data on blue-line prints for parts of the Sierra Nevada and Coast Ranges. In the early 1960's another compilation project from VTM, SV, and Forest Survey data was begun. All of these maps accumulated in the files of the Pacific Southwest Forest and Range Experiment Station. Unfortunately, none of the compilations was complete for any one species. We have used them all, checking them against the original field maps and adding to them from more recent surveys.

Preliminary maps prepared from these sources were the basis for the California distribution of 28 species mapped in *Silvics of Forest Trees of the United States* (Fowells 1965). The same sources were used for the distribution maps of pines native to California prepared by Critchfield and Little (1966). Both sets of maps have recently been issued in a different format by Little (1971). Unfortunately, few significant corrections were made to the Fowells (1965) or Critchfield and Little (1966) maps.

This atlas stems from sources independent of Sudworth's early compilation of tree distribution notes (Sudworth 1908), which was often used as the basis for older maps of California trees. Such maps, extrapolated from a limited number of specific points, are less helpful than the original list of localities on which they were based. Our maps do, however, substantiate the general accuracy of Sudworth's early records. We examined Sudworth's files and checked the origin of some of the questionable reports on California species. Conspicuous discrepancies and errors in the literature are mentioned in the species notes.

Herbarium specimens were used to a limited extent in preparing these maps, especially for those species with little or no vegetation type map data. We made partial checks of the following herbaria: University of California, Rancho Santa Ana, U.S. National, Gray, and Arnold Arboretum. All tree specimens in the Jepson, Humboldt State College, and California Polytechnic College herbaria were checked.

Preliminary versions of our maps were circulated to universities and colleges, government agencies, and other organizations. The staffs of several National Forests, the U.S. Bureau of Land Management, and the Death Valley and Joshua Tree National Monuments provided useful information. The following individuals contributed significantly, encouraging the early phases of the work or adding localities during the review process: Gordon L. Allenbaugh, Kenneth N. Boe, Robert Z. Callaham, J. Robert Haller, Donald V. Hemphill, John Thomas Howell, James L. Jenkinson, LeRoy C. Johnson, Thomas W. Koerber, James I. Mallory, Jack Major, William W. Oliver, Ralph N. Philbrick, Robert F. Powers, Douglass F. Roy, Philip W. Rundel, John O. Sawyer, Clifton F. Smith, Chester O. Stone, Steven N. Talley, John H. Thomas, Dale A. Thornburgh, John M. Tucker, Ernest C. Twisselmann, and Philip V. Wells.

The final versions of the maps were prepared by Audrey E. Kursinski of the Pacific Southwest Forest and Range Experiment Station. We are indebted to her for her major contributions.

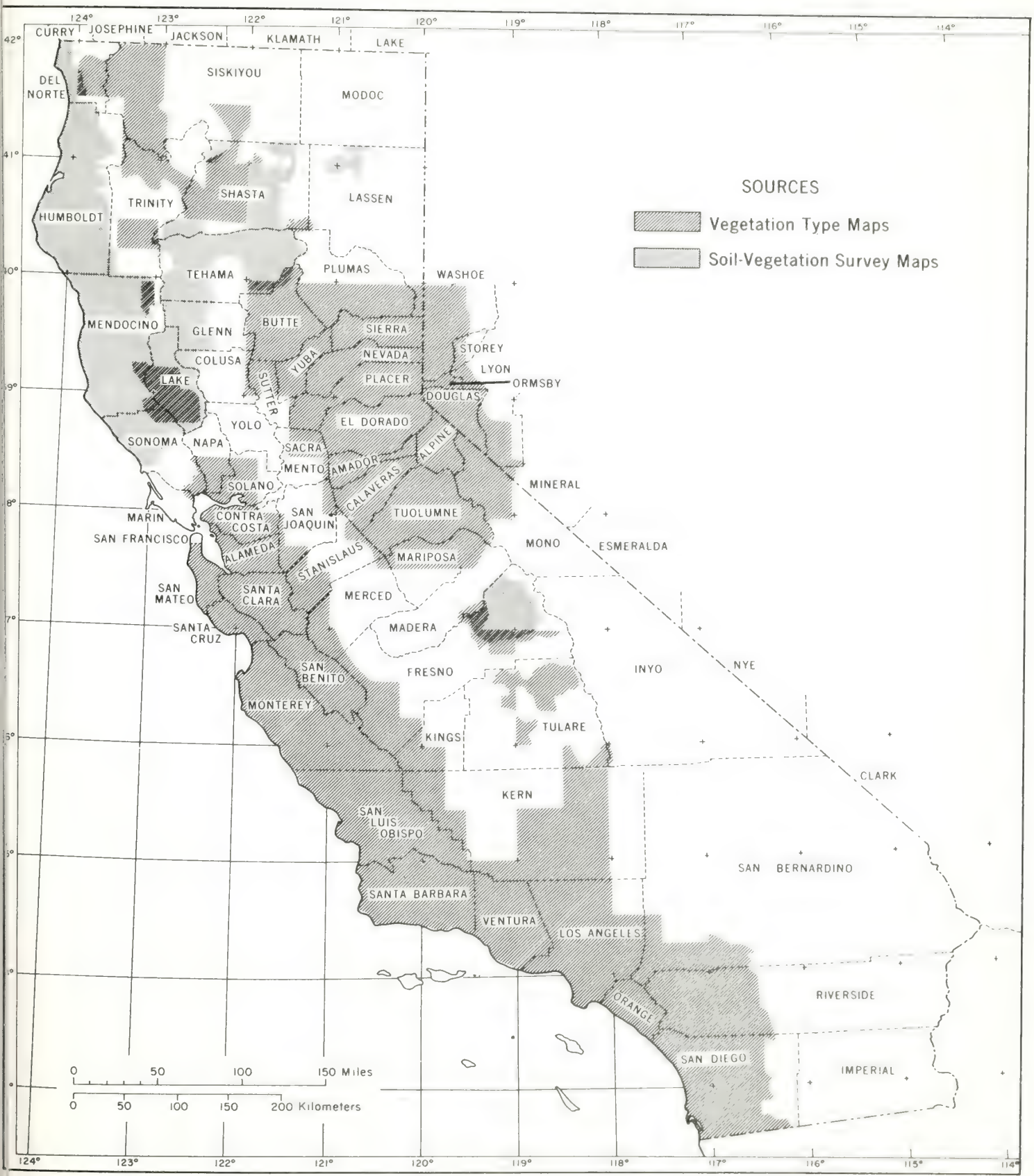


**Figure 3**—County names and coverage of vegetation maps.

## LIMITATIONS OF MAPS

Despite the broad coverage of the VTM and SV surveys, sizable parts of California still have no satisfactory vegetation map coverage *(fig. 3)*. Southwestern Trinity County is a good example. This situation left gaps in the maps of widespread species. We tried to find definite localities within these gaps from herbarium records, published information, personal field observations, and interviews with local experts. We resisted the urge to extrapolate distributions across the larger gaps. Only with the most common species, in areas where we had some field experience, did we extend solid distributions across areas with no vegetation type data. We prefer to show the incompleteness of the field work rather than fill in gaps to improve map appearances. In general, we bridged the gaps with dotted lines. These lines suggest that the species is common within the area but that vegetation type data for the region are incomplete or lacking.

Since the bulk of our data comes from vegetation type surveys, the resulting maps tend to be conservative. A species had to be a conspicuous element of the vegetation before it was listed as part of the "type"—20-percent canopy coverage in the old VTM survey and 5-percent coverage on a 10-acre minimum in the present SV survey. Thus, in a locality shown on our maps as a spot, the tree will most likely be common in the appropriate habitat within the mapped area. It is possible, however, that scattered individuals of the species may be present some distance from the mapped locality. External boundaries of the distributions are more accurately portrayed in the original data and our compilations than are internal boundaries.

The "X's" on the maps refer to three different kinds of data on the California mainland. In some cases an X designates only one isolated tree or at most a few scattered individuals. In other cases the X is based on an herbarium specimen or other record which gives no clue to the size of the population. Also shown as X's are isolated "type" areas less than 2 miles across, which could not be realistically plotted as a spot at the scale of our maps. It would have been desirable to treat these three categories separately. The compilations we used were not consistent, however, and it was impractical to maintain different symbols for each kind of locality. On the California islands, which lack type-map data, an X indicates the presence of the species on the island but not its location.

The ranges of 15 species, either endemics or of limited distribution in the State, are shown at larger scales on insert maps. On the inserts, X's indicate either typed areas less than one-third to one-half mile across or stands of unknown extent.

Since most of the VTM data was gathered in the 1930's, we cannot vouch for the present existence of all mapped localities. This is particularly true of metropolitan southern California, where the distribution of riparian trees is known to have been altered. Where we know that a tree population has been exterminated near the limits of its range—for example, the MacNab cypress stand in Whiskeytown Lake—we have shown the locality as extinct (E). One apparent difficulty may be encountered in relocating mapped localities in the field. The VTM survey crews did much of their field work on foot, and consequently many of their isolated localities cannot be seen from paved, public roads.

Although we have been careful about the reliability of the sources we used, we have probably perpetuated some old errors and created new ones. In general, the accuracy of tree identifications by the VTM and SV surveys was excellent. We found only one gross error on the VTM maps: *Populus trichocarpa* and *P. fremontii,* which probably hybridize and intergrade in places, were sometimes confused.

Although these maps were assembled in the late 1960's—six decades after Sudworth's classic work on western trees—his introductory comment on tree ranges is still as applicable as ever: "Much is yet to be learned of where the trees of this region grow" (Sudworth 1908).

## PLANT COMMUNITIES AND TREE DISTRIBUTION

In the descriptive notes the distribution of each species is presented in its ecological context, including the plant community or communities in which the tree commonly appears. Merriam's "life zones" have often been used for this purpose in the past, but the traditional zones must be so altered and subdivided to fit vegetation patterns in parts of California that they are of limited value. We have adapted the "plant communities" of Munz (1959) with minor modifications, and these names are capitalized in the text. Climate plays a major role in the distribution of these zonal plant communities, although differences in soil parent material or frequent fires may locally override climatic effects.

Species with Pacific Northwest affinities also appear in the "vegetation zones" of Franklin and Dyrness (1969). The plant community names adapted from Munz, together with related vegetation units, are outlined in *table 1*. Some interrelationships between plant communities and tree distribution are considered more fully below.

### *California Woodlands*

The Foothill Woodland covers a vast area around the Central Valley and at lower elevations in the Coast Ranges. In a general way this mixture of open savanna and denser

Table 1—*Comparison of plant communities,*[1] *vegetation zones,*[2] *vegetation types,*[3] *and forest cover types* [4]

| Plant communities | Related vegetation units |
|---|---|
| Foothill Woodland | California oakwoods (K), Digger pine-oak type (SAF) |
| Northern Oak Woodland | Oregon oakwoods (K), Interior valley zone (F&D), Oregon white oak type (SAF) |
| Southern Oak Woodland | |
| Northern Juniper Woodland | Juniper steppe woodland (K), *Juniperus occidentalis* zone (F&D), Western juniper type (SAF) |
| Pinyon-Juniper Woodland | Juniper-pinyon woodland (K), Pinyon-juniper type (SAF) |
| Mixed Conifer Forest (Yellow Pine Forest) | West of the Sierra Nevada-Cascade crest: Mixed conifer forest (K); Mixed conifer zone, *Abies concolor* zone (F&D); Pacific ponderosa pine type, Ponderosa pine-sugar pine-fir type, California black oak type (SAF) |
| westside-pine phase<br>eastside-pine phase<br>mixed phase<br>white fir phase | East of the Cascades: Ponderosa shrub forest (K), *Pinus ponderosa* zone (F&D); Interior ponderosa pine type, white fir type (SAF) |
| Red Fir Forest | Red fir forest (K), *Abies magnifica shastensis* zone (F&D), Red fir type (SAF) |
| Lodgepole Forest | Lodgepole pine type (SAF) |
| Subalpine Forest | Lodgepole pine-subalpine forest (K), *Tsuga mertensiana* zone (F&D) |
| Bristlecone Pine Forest | Great Basin pine forest (K); Bristlecone pine type, Limber pine type (SAF) |
| Mixed Evergreen Forest | California mixed evergreen forest (K), Mixed evergreen zone (F&D), Oak-madrone type (SAF) |
| Douglas-fir Forest | *Tsuga heterophylla* zone (F&D), Pacific Douglas-fir type (SAF) |
| Redwood Forest | Redwood forest (K), Redwood type (SAF) |
| North Coastal Coniferous Forest | Cedar-hemlock-Douglas-fir forest (K); *Picea sitchensis* zone, *Tsuga heterophylla* zone, Port-Orford-cedar variant (F&D); Sitka spruce type, Port-Orford-cedar/Douglas-fir type (SAF) |
| Closed-cone Pine Forest | Pine-cypress forest (K) |

[1]Munz (1959).

[2]Franklin and Dyrness (1969).

[3]"Potential natural vegetation types"—see Kuchler (1964).

[4]Society of American Foresters (1954).

woodland vegetation forms a transition zone between the grassland of the valley plains and the Mixed Conifer Forest of the mountains. The Foothill Woodland is a particularly "Californian" community—four of its common trees are strictly endemic to the State. Many of its shrubs and herbs are also endemic. Blue oak and Digger pine characterize the community. Neither species ranges far beyond the community type. Pure blue oak savannas do spread farther down into the valleys than the pine, while Digger pine woodland reaches higher within the forests than the oak on rocky spots. The other two endemic trees are valley oak and California buckeye. Both have a large portion of their distribution within the Foothill Woodland. In the Sierra Nevada-Cascade foothills, the "live oak" in the community is *Quercus wislizenii;* in the south Coast Ranges it is replaced by *Q. agrifolia.*

In the north Coast Ranges, where blue oak gives way to Oregon white oak, the Foothill Woodland shifts to the Northern Oak Woodland. This poorly defined community occupies the drier, warmer slopes and canyon bottoms within the Mixed Evergreen and Douglas-fir Forests. Although Oregon white oak is a dominant in the Northern Oak Woodland, it has a much broader distribution than the community type.

In southern California, the Foothill Woodland's homolog is the Southern Oak Woodland. Blue oak is replaced by Engelmann oak, and coast live oak assumes greater importance. Knapp (1965) distinguished the live oak woodland of the southern California islands from that of the mainland. Like several other southern California communities, the Southern Oak Woodland has floristic affinities with regions to the east. Some of the *Juglans californica* stands in the Southern Oak Woodland are reminiscent of *Juglans major* within oak woodlands of Arizona and New Mexico.

## Interior Woodlands

The Northern Juniper Woodland occurs to the east of the Mixed Conifer Forest. Western juniper is typically the only tree present. In places, this community is a narrow transition zone between the forested slopes and the sagebrush flats. But in other areas, particularly on the lava flows of the Modoc Plateau, it is an extensive, well developed community. The Northern Juniper Woodland extends northward into Oregon, and many of its plants are typical of interior regions. In the central Pit River drainage, the Northern Juniper Woodland merges with disjunct stands of the Foothill Woodland. In several portions of the Pit and Klamath River drainages, Oregon white oak is associated with western juniper. The geographic separation of Northern Oak Woodland from Northern Juniper Woodland is not great.

South of Lake Tahoe, the desert-border woodland shifts from the Northern Juniper Woodland to the Pinyon-Juniper Woodland. This is the westernmost phase of a huge pinyon and juniper formation in the southwestern United States and northern Mexico. These woodlands occupy the zone between the conifer forest of the higher mountains and the desert scrub of the alluvial fans and valleys. The species of juniper and pinyon involved vary geographically. In California, the common juniper of the Pinyon-Juniper Woodland is *Juniperus osteosperma,* but in the western extreme of the community the shrubby *J. californica* replaces it. The typical pinyon is *Pinus monophylla* except in the south, where it is replaced by *P. quadrifolia.*

## Montane Forests

We have substituted the name Mixed Conifer Forest for Munz's Yellow Pine Forest. "Yellow pine" is not a widely used name for *Pinus ponderosa,* and this single pine species is insufficient to characterize this complex, "mixed" forest type. The Mixed Conifer Forest is the great montane forest formation of the Sierra Nevada-Cascades in California, bordered by the Foothill Woodland on the west and the Northern Juniper and Pinyon-Juniper Woodlands on the east. At higher elevations the Red Fir and related Forests replace the Mixed Conifer Forest.

The Mixed Conifer Forest contains variable combinations of ponderosa pine, incense-cedar, sugar pine, Douglas-fir, white fir, and California black oak. All these species are widely distributed in southern Oregon, but well developed mixtures of all six species are mostly confined to California. In warm, dry western portions of the forest, ponderosa pine usually dominates the community. At times the westside-pine phase is only a narrow transition belt between the Foothill Woodland and the truly mixed phase of the forest at middle elevations. The mixed phase is always a broad and conspicuous part of the forest, but in protected areas—particularly at higher elevations—white fir gradually dominates the mixture. A white fir phase of the mixed community usually lies just below the Red Fir Forest. In the southern Sierra Nevada the relict groves of the giant sequoia occur in and tower over the Mixed Conifer Forest.

On the eastern flank of the Mixed Conifer Forest, relatively pure pine stands reappear. In the north, ponderosa pine dominates the eastside-pine phase. Extensive eastside-pine communities grow on the Modoc Plateau, and only on the higher ridges are there enough white fir or incense-cedar trees to form a mixed forest. These Modoc Plateau eastside-pine stands can be viewed as the southern extreme of the interior Oregon pine forests. From Lassen County southward, Jeffrey pine increasingly replaces ponderosa pine in the eastside-pine phase. In Mono County extensive stands of Jeffrey pine occur, and Jeffrey pine forest is well developed on the Kern Plateau.

In the Klamath Mountains, Mixed Conifer Forest appears locally in typical form. North and west of the Pit River, Douglas-fir is often a more important part of the mixture. Hardwoods also increase in dominance, and the Mixed Conifer Forest merges with the Mixed Evergreen Forest.

In southern California, the Mixed Conifer Forest occurs on the higher ridges in a more typical form than in the depleted disjunct stands of the south Coast Ranges. Douglas-fir is absent in southern California. Bigcone Douglas-fir does not effectively replace it except in local, lower-elevation situations. Coulter pine is often added to the lower portion of the southern California Mixed Conifer Forest.

The Mixed Conifer Forest and the higher-elevation forests are not clearly separated formations, for both are characterized by tall conifers. The Red Fir Forest is dominated by almost pure stands of red fir over large areas. Jeffrey and western white pines are minor elements in the fir communities. In the Cascades, and especially in the Siskiyou Mountains, red fir is gradually replaced by noble fir, suggesting the northern affinity of the Red Fir Forest. Other northern conifers just entering California in the high-elevation forests of the Siskiyou Mountains are: Pacific silver fir, subalpine fir, Alaska-cedar, and Engelmann spruce.

The Lodgepole and Subalpine Forests may not be worth distinguishing from each other in some cases. They lie between the Red Fir Forest and timberline. Lodgepole pine communities dip down into the Red Fir and Mixed Conifer Forests around lakes and wet meadows. The most characteristic subalpine trees in California are whitebark pine and mountain hemlock. Neither species grows in the poorly defined Subalpine Forest on the highest southern California peaks.

The desert ranges of southeastern California high enough to support forest above the Pinyon-Juniper Woodland lack any form of the Mixed Conifer Forest. Instead they are covered with the western fringe of an extensive interior mountain community, the open Bristlecone Pine Forest. Bristlecone pine and limber pine characterize this forest. Limber pine continues westward, and is part of the Subalpine Forest at the southern and eastern borders of this community. The Rocky Mountain white fir colonies in the eastern Mojave also fit into this pattern of interior species entering southeastern California.

## Coastal Forests

The Mixed Evergreen and closely related Douglas-fir Forests are very important in the Klamath Mountains and north Coast Ranges east of the Redwood Forest. These communities extend well into southwestern Oregon in their typical California form. Madrone and tanoak are conspicuous in the Mixed Evergreen Forest, less important in the Douglas-fir Forest. Giant chinquapin is widely scattered, and several oaks—particularly canyon live oak—are important in the type.

In a restricted sense, the Mixed Evergreen Forest reappears in the Mixed Conifer Forest of the northern Sierra Nevada. This high-precipitation part of the Sierra Nevada has a large distribution of madrone. Within the madrone region is a smaller distribution of tanoak, and in the central portion of the tanoak range is a small population of giant chinquapin. Many understory plants from the coastal forests also appear in this mesic, northern Sierra Nevada region.

Douglas-fir is not important in the coastal forests south of the Santa Cruz Mountains, and the Mixed Evergreen Forest of the south Coast Ranges becomes more of a mixed hardwood forest without conifers, although Coulter pine is a minor element in places. As tanoak and madrone drop out, the southern extremes of the community are essentially reduced to coast live oak forest.

The North Coastal Coniferous Forest is a heterogeneous group of forest types that are well developed in the north, but are difficult to recognize in their southern extremes in California. Sitka spruce and grand fir form one phase of these northern forests at low elevations. The spruce is conspicuous between the coast and the Redwood Forest. Grand fir continues further inland into the redwood belt. Western hemlock is scattered in the Redwood Forest and locally dominates the Douglas-fir Forest. Western red-cedar is restricted to very moist, sometimes boggy habitats within the same general region.

The Closed-cone Pine Forest consists of disjunct stands of closely related closed-cone pines and closed-cone cypresses. These groves of pines, cypresses, or both, are scattered along the coastline and on the southern California islands. A special phase, which includes bishop pine, the "Bolander" form of shore pine, and Mendocino cypress, grows on sterile, podzolized soils in Mendocino County. A tiny homolog of this phase occurs on the Monterey Peninsula, where bishop pine and Gowen cypress are mixed together on a similar soil situation. Bishop pine also grows in pure stands in a number of areas. Monterey pine forms relatively pure stands, with scattered coast live oaks. Monterey pine does not really form mixed communities with either of the two cypresses that occur on the Monterey Peninsula. Knapp (1965) included the southern California Torrey pine groves as a part of his California coastal closed-cone pine and cypress forests.

A series of more inland pine-cypress communities is related to the coastal Closed-cone Pine Forest. In these inland stands, knobcone pine replaces bishop and Monterey pines and Sargent and MacNab cypresses replace the Mendocino cypress. These inland trees also have closed cones.

## Riparian Forests

Munz (1959) did not discuss any riparian forest communities, but distinctive communities are found along portions of many streams. So many dominant species are involved over such a wide elevational range that it is difficult to characterize riparian community types. Yet three general types are apparent. The first type is a group of distinctly "Californian" communities. They grow along larger streams flowing from the lower portion of the Mixed Conifer and Mixed Evergreen Forests through the Foothill Woodland, out into the valleys. California sycamore, California boxelder, and Fremont cottonwood are important at lower elevations, together with several willows. Knapp (1965) called this community the *California sycamore bottomland woods.* At higher elevations bigleaf maple may be present, and white alder becomes dominant in what Knapp (1965) called the *California white alder bottomland woods.* On the fertile valley flood plains, valley oak may be part of the riparian forest (Thompson 1961). Hinds walnut is important along the lower Sacramento River.

In the second type of riparian community, species from the north are conspicuous. Red alder along the coastal streams is a good example. Black cottonwood also grows along the coastal streams and reappears at higher elevations in the mountains. Oregon ash might be put in this group.

The third type includes species that are related to widespread continental communities. Included here are narrowleaf cottonwood, water birch, and velvet ash. The few California colonies of western hackberry are not in riparian forests, but they survive in moist spots and are related to this group.

# SPECIES NOTES

## *Abies* firs

**(Pinaceae Pine Family)**

About 40 species of firs have been described in the Northern Hemisphere. Of the nine species native to the United States and Canada, seven grow in California and are mapped in this atlas. One species, bristlecone fir, is endemic to California.

**Abies amabilis** (Dougl.) Forbes
*Pacific silver fir* *Map 1*

This fir is common in the Olympic and Cascade Mountains of the Pacific Northwest, but rare in California (Fowells 1965). In the north it grows in the cool, wet forests of the "*Abies amabilis* zone" (Franklin and Dyrness 1969). South of Crater Lake, Oregon, Pacific silver fir is found only as isolated groves in western Siskiyou County, California. In 1928, Roxana S. Ferris and Doris K. Kildale collected Pacific silver fir near Hancock Lake in the Marble Mountains but labeled their specimens *A. lasiocarpa* (Gillespie 1931). While mapping for the VTM survey in 1932, Alfred K. Crebbin mapped and correctly identified *A. amabilis* stands near Hancock Lake and Ukonum Lake. Haddock (1961) later publicized these two localities. They were described in greater detail by Lewis (1966). Additional stands were discovered in the Siskiyou Mountains between Copper Butte and Joe Creek by Eugene L. Parker in 1961. The California stands range from 5,600 to 7,000 feet elevation.

Other references: Sawyer and Thornburgh 1969.
Personal correspondence: Eugene L. Parker, Sept. 25, 1961; June 10, 1970.

**Abies bracteata** D. Don
*bristlecone fir, Santa Lucia fir* *Map 2*

Bristlecone fir is the rarest and most unusual fir in North America. It is found only in parts of the Santa Lucia Mountains, California. Here it is locally common within the Mixed Evergreen Forest above the Redwood Forest. The fir tends to be concentrated in steep, rocky, fire-resistant spots at elevations from 2,000 to 5,000 feet. The most inland stand, 13 miles from the Pacific Coast, is in Anastasia Canyon.

The southern limit has been listed as San Carpoforo Creek, in or near San Luis Obispo County (Jepson 1910, Van Rensselaer 1943), but the existence of these stands has been questioned (Howitt and Howell 1964, Little 1971). Olson (1968b) photographed a bristlecone fir population on Marmolejo Creek, 7 miles into San Luis Obispo County. A 1927 specimen collected by Chester Dudley on "upper Las Tablas Creek" (Hoover 1970) would be from a locality several miles farther south, but we have no confirmation of this locality.

We also have no confirmation of local rumors that the fir grows as far north as Danish Creek or Mount Carmel. The northernmost tree recorded by the VTM was on Skinner Ridge. It may not have survived the last fire in that area. Shreve's (1927) record of this fir at the 750-foot elevation on the North Fork of the Little Sur River is questionable, and the stand cannot be relocated. One disjunct colony of fir does grow at the 600-foot elevation on the Big Sur River near Ventana Camp.

In 1831, Thomas Coulter collected bristlecone fir on the ridge west of Mission San Antonio. The following year, David Douglas probably found the fir at the same locality. Both botanical explorers sent their specimens to Europe, and competing names *(bracteata* versus *venusta)* were published in 1836. The name based on Coulter's material appeared slightly earlier.

Other references: Eastwood 1897, Griffin 1968, Olson 1968a, Talley 1970.
Personal Correspondence: Neil Havlik, Sept. 24, 1970.

**Abies concolor** (Gord. & Glend.) Lindl. (*lowiana* [Gord.] A. Murr.)
*California white fir, white fir* *Map 3*

White fir is widely distributed in the western United States from southern Oregon to New Mexico, and south into Mexico (Fowells 1965). The California form of this variable fir is sometimes considered a separate variety or species.

In California, white fir is common—often dominant—in the higher-elevation phases of the Mixed Conifer Forest. Near its upper limits, white fir is often associated with red fir, but the two species are not known to hybridize in nature. White fir is the only fir in the depauperate Mixed Conifer Forest of the Warner Mountains. Several colonies survive near springs in the barren range east of the Warner Mountains in northwestern Nevada (Critchfield and Allenbaugh 1969). White fir is strangely absent from the relict stands of Mixed Conifer Forest in the Santa Lucia Mountains. Shreve (1927) erred in listing it as native to this mountain range.

The Clark and Kingston Mountain stands in the Mojave Desert are closely related to the Rocky Mountain form of white fir, which differs from California white fir in its morphological and chemical characters. To a lesser degree this interior fir influence is evident in other southern California populations as far north as the Tehachapi Mountains.

In northwestern California, white fir is increasingly influenced by grand fir. These intermediate stands occur in the same montane habitats as white fir farther south. They are a minimum of several miles inland and at least 1,000 feet higher than typical grand fir (see section on grand fir). The influence of grand fir is evident as far south as the mountains of Humboldt and Trinity Counties. Traces of grand fir also extend east to the Warner Mountains. On two occasions in recent years, fir logs with red bark like that of grand fir have

been observed there, but no intact trees with red bark have been found yet.

Other references: Applegate 1938, Clokey 1951, Daniels 1969, Grinnell 1908, Grinnell and Storer 1924, Hamrick 1966, Hemphill 1952, Howell 1940-42, Little 1966a, Miller 1940, Milligan 1968, Raven 1950-53, Roof 1969a, Wells and Berger 1967, Wolf 1938.

**Abies grandis** (Dougl.) Lindl.
*grand fir* *Map 4*

Grand fir is common at middle elevations in the interior mountains of the upper Columbia River basin from northern Idaho to British Columbia. It is also widely distributed in western Washington and Oregon at lower elevations (Fowells 1965, Franklin and Dyrness 1969). Farther south, in California, it is increasingly restricted to the vicinity of the coast, where it grows in lower-elevation, more temperate habitats than stands of white fir or white fir-grand fir intermediates (see section on white fir).

In this coastal strip, grand fir is scattered in the North Coastal Coniferous Forest and the Redwood Forest, usually below 2,000 feet. It is also found in the Closed-cone Pine Forest on the immediate coast. Joseph P. Tracy noted one stand unusually far inland in Humboldt County, on the Van Duzen River near Dinsmores. The most interior outpost of grand fir found by the SV survey was on Asbill Creek at 2,000 feet elevation in northeastern Mendocino County. The traditional southern limit has been near Fort Ross, but Knight (1965) recently discovered grand fir south of the Russian River on Willow Creek. Sudworth's (1908) reports of grand fir at elevations above 3,000 feet in Humboldt County were probably based on intergrades with white fir.

Other references: Powell 1968, Tracy (n/d).

**Abies lasiocarpa** (Hook.) Nutt.
*subalpine fir* *Map 5*

This is the most widely distributed fir in North America, scattered from Alaska to southern Arizona (Fowells 1965). In the interior, subalpine fir often forms the highest elevation forest zone, but toward the coast it is ecologically replaced by the "*Tsuga mertensiana* zone" (Franklin and Dyrness 1969). Subalpine fir ranges south along the Cascades as far as the Mountain Lakes Wilderness Area in Oregon, often in high-mountain valley bottoms and frost pockets. Farther south in Oregon only one small, shrubby colony is known, on Mount Ashland (Waring 1969). This tiny stand probably furnished the basis for Sudworth's (1908) report of subalpine fir on the north side of the Siskiyou Mountains.

This species was not known to extend south into California until 1969, when Sawyer, Thornburgh, and Bowman (1970) discovered it on Russian Peak. They found healthy, expanding populations in the Sugar Lake and Duck Lake basins at elevations from 5,800 to 6,000 feet. These relict stands of fir are surrounded by larger populations of Engelmann spruce.

For several years questions have arisen about the identity of several fir colonies in the Marble Mountains, particularly near Deep Lake. One suggestion was that they were *A. amabilis*, which does occur elsewhere in the Marble Mountains. But after comparing Deep Lake and Russian Peak material, Donald Hemphill now states that the Deep Lake firs are *A. lasiocarpa*. It is possible that other Marble Mountain fir colonies may also be *A. lasiocarpa*. The Deep Lake locality is not shown on Map 5.

Other references: Lewis 1966, Sawyer and Thornburgh 1969, 1970.
Personal correspondence: Donald V. Hemphill, Jan. 25, 1972.

**Abies magnifica** A. Murr. (including var. *shastensis* Lemm., Shasta red fir)
*California red fir, red fir* *Map 6*

In California, *Abies magnifica* dominates the Red Fir Forest of the Sierra Nevada-Cascade Ranges. From Lassen Peak, California, to the vicinity of Crater Lake, Oregon, red fir is usually represented by var. *shastensis*, which has cones with partly exserted bracts. In this region the influence of noble fir (an exserted-bract species) is increasingly evident from south to north and from east to west. North of about 44° north latitude, Shasta red fir is completely replaced by typical noble fir. There are no sharp geographic boundaries within this species complex, and we have shown red and noble fir distribution on the same map. In general, however, the high-elevation firs north and west of the Klamath River resemble noble fir more than red fir. Below the Klamath River the high-elevation firs are more consistently Shasta-like. The Coast Range arm of Shasta red fir distribution extends southward to Snow Mountain in Lake County (Hemphill 1952).

In the northern and central Sierra Nevada the hidden-bract cone type prevails. But in the southern Sierra Nevada red fir again has cones with exserted bracts. The southern limit of the species is on Sunday Peak, just into Kern County (Twisselmann 1967).

We have little information on the extent of red fir on the eastern slopes of the Sierra Nevada. It is probably more common in Inyo and Mono Counties than our map suggests. Oosting and Billings (1943) stated that red fir does not occur east of Mount Rose, Nevada, but the VTM survey found one disjunct locality in the Virginia Range, some 10 miles east of Mount Rose. Red fir is absent from the high-elevation fir forest of the Warner Mountains.

Other references: Franklin 1964, Howell 1940-42, 1946-49, Little 1966a, Parker 1963, Raven 1950-53.

**Abies procera** Rehd.
*noble fir* *Map 6*

Noble fir is widespread in the higher elevation forest of the Washington and Oregon Cascades (Fowells 1965). There it is

important in the "*Abies amabilis* zone" and is scattered up into the "*Tsuga mertensiana* zone" (Franklin and Dyrness 1969). Typical noble fir does not extend south into California, but intermediate forms between noble fir and the Shasta form of red fir are common in the Siskiyou Mountains (Franklin 1964, Parker 1963). (See section on red fir.) A few stands with noble fir characteristics have been found in the Marble Mountains (Lewis 1966). According to Sawyer and Thornburgh (1969), the largest "noble fir" stand south of the Klamath River may be on North Trinity Mountain, Humboldt County. Individual trees with some noble fir-like characters are widely scattered in the Shasta red fir forests of the north Coast Ranges and Klamath Mountains. Baker (1954) collected one such specimen as far south as Black Butte, Glenn County.

## *Acer* maples

**(Aceraceae Maple Family)**

Some 120 tree and shrub species of maples are recognized in the Northern Hemisphere. One species crosses the Equator to Java. Thirteen species grow in North America, with four ranging into California. Two of the California species are typically trees. Neither *Acer circinatum* Pursh nor *A. glabrum* Torr. is predominantly of tree size or form in California, and they are not mapped.

### **Acer macrophyllum** Pursh

*bigleaf maple* *Map 7*

Bigleaf maple is common along the Pacific Coast from British Columbia to southern California (Fowells 1965). Sargent (1891) and Jepson (1910) listed the extreme southern limit as Hot Springs Valley[1] in San Diego County, but the southern limit shown on our map is based on a single tree found in 1969 growing at Oasis Spring in the Laguna Mountains. Bigleaf maple survives on Santa Cruz Island (Munz 1935). The Sierra Nevada distribution extends south to Sequoia National Park (Rockwell and Stocking 1969), but it is not common south of Mariposa County. No localities east of the Sierra Nevada-Cascade crest came to our attention.

In southern and central California this species is usually riparian. In the northern Sierra Nevada, and particularly in the north Coast Ranges and Klamath Mountains, bigleaf maple is more generally distributed, scattered on shady uplands well away from the streams. This maple spans a broad elevational range in the mountains. In contrast to *Acer negundo*, bigleaf maple does not extend down into the riparian forests along the Central Valley rivers (Jepson 1910).

Bigleaf maple seldom appeared on vegetation type maps. Our compilation is too generalized in northern areas, and in the south all of the scattered riparian localities could not be shown.

[1]See Geographic Location of Place Names, footnote 1, for comment on this place name.

Other references: Boughey 1968, Bowerman 1944, Grinnell 1908, Howell 1940-42, 1970, Howitt and Howell 1964, Knight, Knight, and Howell 1970, Lewis and Gause 1966, Peterson 1966, Powell 1968, Raven and Thompson 1966, Ripley 1969, True 1970, Twisselmann 1967.
Personal communication: Reid Moran, Oct. 12, 1970.

### **Acer negundo** ssp. **californicum** (T. & G.) Wesmael

*California boxelder* *Map 8*

Boxelder, including its various races, is found throughout much of the United States and south central Canada (Little 1971). It seems to be naturally absent from Oregon and Washington although now widely planted there (Peck 1961). The California subspecies is confined to the State. Here boxelder is usually riparian, often at relatively low elevations. In contrast to bigleaf maple, boxelder follows streams out into the Central Valley. An isolated stand on Yreka Creek in Siskiyou County is far north of the Sacremento Valley distribution (Jepson 1909-36). Although the species may be common along a given stream–for example, the San Lorenzo River in Santa Cruz County–it is not found on all streams in a region. The species seldom appeared on VTM maps.

Other references: Boughey 1968, Bowerman 1944, Howell 1970, Howitt and Howell 1964, Munz 1935, Peterson 1966, Rubtzoff 1953, Twisselmann 1967.
Personal communication: Reid Moran, Oct. 12, 1970.

## *Aesculus* buckeyes

**(Hippocastanaceae Buckeye Family)**

There are 13 species of buckeyes, all in the Northern Hemisphere. Seven are native to North America, and California has one species, an endemic. Although California buckeye is not always of tree stature, it is mapped in this atlas. A more shrubby species, *Aesculus parryi* A. Gray, occurs in Baja California and grows to within a few miles of the California state line. The California buckeye is more closely related to Asiatic species than to *A. parryi* (Hardin 1957).

### **Aesculus californica** (Spach) Nutt.

*California buckeye* *Map 9*

A large portion of California buckeye's range lies within the Foothill Woodland which encircles the Central Valley. Although sometimes shrubby, buckeyes in favorable habitats may exceed 45 feet in height. A few individuals appear along stream beds well out onto the floor of the valley–for example, near Modesto. Some colonies reach up to 5,200 feet elevation on Lockwood Creek in Fresno County. The general upper limits of buckeye in the Sierra Nevada, mapped by Vansell, Watkins, and Hosbrook (1940), are shown on Map 9 as a solid line. Jepson (1891) listed buckeye for the Sutter Buttes in the Sacramento Valley, and we have shown it there, although this

occurrence was not confirmed by the VTM survey. The southern limit of the Sierra Nevada-Tehachapi Mountains distribution is on the edge of Antelope Valley in Los Angeles County. We have omitted from the map an isolated occurrence at a spring below Pigeon Pass, on the northeast side of the Box Springs Mountains near Riverside, which Frank C. Vasek suggests was planted by Indians. Buckeye is absent from Santa Barbara County. A few isolated trees were noted by VTM survey crews in northwestern San Luis Obispo County, but significant Coast Range populations start in Monterey County.

In the southern part of its range buckeye tends to form thickets on steep north slopes. In the north, it often grows on rocky canyon bottoms or south aspects. In Humboldt County buckeye continues much farther west than the Foothill Woodland. It is scattered across the Mixed Evergreen and Redwood Forests into the cool, wet Mattole River region. Scattered trees grow on the old terraces along the lower Trinity River between Hawkins Bar and Salyer. Jepson (1910) and Sargent (1926) mentioned buckeye on the South Fork of the Salmon River in Siskiyou County, but we could find no confirmation of this locality even in Jepson's field notes. The single locality in northern Trinity County is based on an old report of buckeye on Canyon Creek (Eastwood 1902), and has no recent confirmation. Jepson (1909-36) reported buckeye in the Sacramento River Canyon near the Shasta-Siskiyou county line.

Other references: Behr 1891, Buttery and Green 1958, Benseler 1968, Eastwood 1902, Hardin 1957, Hoover 1970, Howitt and Howell 1964, Klyver 1931, McClintock and Knight 1968, Parish 1894, Ripley 1969, Roof 1959, Sargent 1926, Stebbins 1968, Twisselmann 1967.
Personal correspondence: Frank C. Vasek, June 10, 1970.

## *Alnus* alders

**(Betulaceae Birch Family)**

About 30 species of shrub and tree alders have been described. With the exception of one Andean species, all are in the Northern Hemisphere. Of the 10 species in North America four range into California. Neither *Alnus sinuata* (Reg.) Rydb. nor *A. tenufolia* Nutt. is predominantly of tree size or form in California, and neither was mapped.

**Alnus rhombifolia** Nutt.
*white alder* *Map 10*

White alder ranges from southern California northward to southern British Columbia and eastward to Idaho. In California it is strictly riparian, and restricted to the most permanent streams. Thus, Jepson (1910) speaks of white alder as a more reliable sign of water than either sycamore or cottonwood. It spans a great elevational range—from below 100 feet to over 8,000 feet (Jepson 1910). White alder follows some Sierra Nevada streams out of the foothills into the edge of the Central Valley. Twisselmann (1967) mentions one isolated colony along the Kern River surprisingly near Bakersfield.

In northern California white alder is absent from the immediate coast, where it is replaced by red alder. White alder is the only alder in southern California. East of the Sierra Nevada-Cascade crest white alder is rare. White alder is scattered on several creeks west of Susanville. The VTM survey found one small stand one mile northwest of Genoa, Nevada, and collected a specimen west of Pyramid Lake.

Other references: Boughey 1968, Bowerman 1944, Grinnell 1908, Higgins 1952, Hoover 1970, Howell 1940-42, Parish 1930, Raven and Thompson 1966, Roof 1959, Thomas 1961, Tracy (n/d).
Personal communication: Charles J. Kraebel (n/d).

**Alnus rubra** Bong.
*red alder* *Map 11*

Red alder grows abundantly in a narrow strip along the Pacific Coast from San Luis Obispo County northward to southeastern Alaska. Many references report red alder in the Santa Ynez Mountains of Santa Barbara County, but these reports seem to be based on white alder (Smith 1952, Van Rensselaer 1948).

Although often riparian, red alder does grow on moist uplands within the coastal fog zone in northern California. North of San Francisco isolated colonies of red alder probably grow much farther inland than our type map sources suggest.

Other references: Fowells 1965, Howell 1970, Hoover 1970, Little 1971, Powell 1968, Thomas 1961, Tracy (n/d).

## *Arbutus* madrones

**(Ericaceae Heath Family)**

About 20 tree and shrub species of madrones are recognized. Three species grow in North America, with one ranging into California. Outside California the closest madrone species is *Arbutus arizonica* (A. Gray) Sarg. in southern Arizona (Little 1950).

**Arbutus menziesii** Pursh
*madrone, Pacific madrone* *Map 12*

Madrone grows from southwestern British Columbia to southern California (Fowells 1965). The relict stands in southern California are few and far between (Axelrod 1967b). The extreme southern limit is near Palomar Mountain, San Diego County (Jepson 1910, Meyer 1931). Sudworth (1908) reported a few shrubby individuals in the Santa Monica Mountains, but there is no recent mention that this colony still survives (Raven and Thompson 1966). One relict stand exists on Santa Cruz Island (Axelrod 1967b).

From the Santa Lucia Mountains northward madrone becomes common and is an important part of the Mixed Evergreen Forest. It is also widespread in the Redwood and

Douglas-fir Forests. Scattered populations extend across the Klamath Mountains into the McCloud-Pit River drainage. In southern Shasta County there are colonies on Clover Creek and the North Fork of Battle Creek. There seems to be a distinct gap across eastern Tehama County. Madrone is fairly common in the northern Sierra Nevada in the lower portion of the Mixed Conifer Forest between Butte and Calaveras Counties. The southern limit in the Sierra Nevada appears to be Sudworth's (1908) report of this species on Pilot Ridge.

Other references: Behr 1896, Boughey 1968, Bowerman 1944, Eastwood 1896, Howell 1970, Howitt and Howell 1964, McClintock and Knight 1968.
Personal correspondence: E. Bruce Barron, Sept. 25, 1970.

## *Betula* birches

**(Betulaceae Birch Family)**

About 40 species of birches have been described in the Northern Hemisphere. At least seven tree species occur in North America. Two birches grow in California. *Betula glandulosa* Michx., a relatively rare shrub in montane, boggy habitats in northern California, is not mapped. Water birch is a marginal "tree" in California, although clearly of tree stature in much of its range.

**Betula occidentalis** Hook. (*fontinalis* Sarg.)
*water birch* *Map 13*

Water birch ranges widely through the interior mountains from western Canada south to Arizona and New Mexico. California is on the western fringe of its main distribution. This birch grows near springs and permanent streams in a few Mojave Desert spots—for example, in Jail Canyon, Panamint Mountains, at 8,500 feet elevation. The White Mountains also have a few birch colonies at elevations of 5,500 to 8,000 feet (Lloyd and Mitchell 1966). The main concentration of water birch colonies is on the east side of the southern Sierra Nevada. Here most creeks running into the Owens Valley between Laurel Creek, Mono County, and Olancha Creek, Inyo County, are lined with water birch (Maciolek and Tunzi 1968, Major and Bamberg 1963, McMinn 1951). The southernmost eastside Sierra Nevada locality that we know of is Haiwee Creek (Davidson 1911). Although Sudworth (1908) and others have reported birch in Kern County, Twisselmann (1967) was unable to confirm these rumors. A few disjunct colonies of birch appear on the west side of the Sierra Nevada in the upper Kings and Kern River drainages (Jepson 1910, McMinn 1951, Rockwell and Stocking 1969).

North of Mono County is a huge gap in the distribution of this birch. The next reported birch localities to the north involve the Feather River area in Butte and Plumas Counties (McMinn 1951). These reports may be based on *Betula glandulosa,* which does grow in this region. We have not found any Feather River specimens of water birch.

Both water birch and *B. glandulosa* have been found in the Warner Mountains. A number of scattered populations of water birch appear in the upper Sacramento, Shasta, Scott, and Salmon River drainages. Additional Siskiyou County specimens came from Seiad and Cottonwood Creeks. Jepson (1909-36) collected this species on Grouse Creek in Humboldt County. Several of these northern California stands must follow streams down almost to the 2,000-foot elevation.

Other references: Clokey 1951, Roof 1969a, Wells and Berger 1967.

## *Castanopsis (Chrysolepis)* chinquapins

**(Fagaceae Beech Family)**

Some 30 species of chinquapins have been described, mostly in tropical Asia. Only two species grow in North America. Both are found in California. One species—giant chinquapin—can be a tree or a shrub. It is mapped in this atlas. The other species, *Castanopsis sempervirens* (Kell.) Dudl., is always a shrub. Hjelmqvist (1948, 1960) separated the North American species from the main Asian group under the name *Chrysolepis.* This new genus has not yet received wide recognition in California.

**Castanopsis chrysophylla** (Dougl.) A. DC. (including the shrubby var. *minor* Benth. golden chinquapin)
*giant chinquapin* *Map 14*

This species ranges from San Luis Obispo County northward to southwestern Washington. In California the tree form is well developed only from Marin County northward (Roof 1969b, 1970). Giant chinquapin trees are widely scattered in the Redwood and Mixed Evergreen Forests. The shrub form is found throughout the range of the species, usually in sterile chaparral habitats. Old references to *Castanopsis chrysophylla* in southern California—for example, in the San Jacinto Mountains (Sargent 1926)—are based on *C. sempervirens.*

In western Siskiyou County the shrub form of *Castanopsis chrysophylla* overlaps that of *C. sempervirens.* The two species probably hybridize in such areas. Cooke (1940) reported *Castanopsis chrysophylla* as an important part of the chaparral on Mount Shasta. Perhaps *Castanopsis* shrubs at lower elevations show some *C. chrysophylla* influence, but typical *C. chrysophylla* shrubs do not seem to grow on Mount Shasta.

A notable disjunct population of giant chinquapin is in El Dorado County, near the Blodgett Forest, where chinquapin trees are scattered within the mesic Mixed Conifer Forest together with tanoak and madrone. The mixture is reminiscent of the coastal occurrences of giant chinquapin.

Other references: Eastwood 1902, Howell 1970, Oberlander 1953, Powell 1968, Shreve 1927, Thomas 1961, Wells 1962.
Personal correspondence: Kenneth Beatty, Nov. 13, 1970.

## *Celtis* hackberries

**(Ulmaceae Elm Family)**

About 70 tree and shrub species of hackberries grow in both temperate and tropical regions. Of the seven species in North America, five are trees. Only one, a small tree, ranges into California.

**Celtis reticulata** Torr. (*douglasii* Planch.)
*western hackberry, netleaf hackberry* *Map 15*

This hackberry occurs in moist spots throughout the drier parts of North America. It is scattered from western Washington south to Arizona, Texas, and northern Mexico. California is on the western margin of the main hackberry distribution. This situation resembles that of water birch, but of the two species, hackberry is rarer in California.

The southernmost colony is in Thing Valley, San Diego County. Another grows near Banning in Riverside County. Several groves are mapped in the mountains of the Mojave Desert, and there are probably other desert localities. In Kern County a group of colonies is found in the Caliente-Tehachapi area, and another colony grows at Democrat Hot Springs on the Kern River (Twisselmann 1967). The northernmost recorded outpost in California is near Independence in Inyo County.

Other references: Adams 1957, Clokey 1951, McMinn 1951.

## *Chamaecyparis* false-cypresses

**(Cupressaceae Cypress Family)**

All the false-cypresses are forest trees. Three species are native to Japan, Taiwan, or both. In North America three species are recognized. Two extend into California. The third American species is scattered along the Atlantic and Gulf Coasts. False-cypresses are closely related to the true cypresses and have been included in *Cupressus* in the past.

**Chamaecyparis lawsoniana** (A. Murr.) Parl.
*Port-Orford-cedar* *Map 16*

Port-Orford-cedar's northern limit is near Coos Bay, Oregon. The species extends south about 220 miles to the central Mad River drainage in Humboldt County. Fowell's (1965) statement of a total range spread of 130 miles is in error. Reports (Knight 1970, Roof 1959) that Port-Orford-cedar grows south of Ferndale are questionable.

In both Oregon and California this species is mixed into a wide variety of forest communities (Franklin and Dyrness 1969). In California it associates with *Thuja plicata* in wet coastal sites near the mouth of the Klamath River. It continues eastward through the Redwood, Douglas-fir, and Mixed Evergreen Forests. Away from the coast Port-Orford-cedar increasingly appears on serpentine soils. The eastern limit of the main distribution is near Indian Creek north of Happy Camp.

Port-Orford-cedar reappears farther inland on the upper Trinity and Sacramento River systems, predominantly on serpentine soils. Although not conspicuous, it is common on the west side of the Sacramento River Canyon from Scott Camp Creek south to Shotgun Creek. It is probably more common on the upper reaches of the Trinity and East Fork of the Trinity Rivers than our incomplete data indicate.

**Chamaecyparis nootkatensis** (D. Don) Spach
*Alaska-cedar* *Map 17*

Alaska-cedar occupies a coastal strip from Prince William Sound, Alaska, south through British Columbia (Fowells 1965). In Washington it is an important tree in the "*Tsuga mertensiana* zone" of the western Cascades (Franklin and Dyrness 1969). In Oregon it continues down the Cascades, finally disappearing south of the divide between the Rogue and Umpqua Rivers.

Alaska-cedar is rare in California. In 1939 it was discovered by Oliver V. Matthews on Mount Emily and by Doris G. Niles on Little Grayback (Mason 1941). Whittaker (1961) later noted it on Preston Peak. Several colonies occur on the Oregon side of the Siskiyou Mountains, one on Whiskey Peak (Sargent 1926). In recent years several additional localities have been found in the Preston Peak region, the southernmost at Elk Hole. In most of these southern localities, the trees are relatively small—at times forming almost a ground cover. One of the better stands covers a north-facing cirque above Bear Lake at 5,000 feet.

Other references: Sawyer and Thornburgh 1969.
Personal correspondence: Donald V. Hemphill, Nov. 11, 1970; John O. Sawyer, July 29, 1970, July 6, 1971.

## *Cornus* dogwoods

**(Cornaceae Dogwood Family)**

*Cornus* is a genus of small trees, shrubs, and rarely herbaceous perennials. It has some 40 species in the Northern Hemisphere, with one species south of the Equator in Peru. About 16 species grow in the United States, six in California. Only one of the latter is consistently tree-like. The other species are mostly riparian shrubs.

**Cornus nuttallii** Audubon
*Pacific dogwood* *Map 18*

Pacific dogwood is a small tree, sometimes a shrub. It ranges north to British Columbia and east to central Idaho. In California, this dogwood is most abundant in the north Coast Ranges, Klamath Mountains, and northern Sierra Nevada. This species thrives in the understory of coniferous forests. Since it is seldom dominant in a community, it does not often appear on vegetation type maps, and the map in this atlas is rather incomplete.

In the Coast Ranges from Marin County southward, Pacific

dogwood is rare. One possibly native tree was found on Mount Tamalpais and there has been one unconfirmed report of trees on Bolinas Ridge (Howell 1970). A locality near Russ Gardens in San Francisco (Behr 1891) has long been extinct. One tree, supposedly native, survives above Glenwood in Santa Cruz County (Thomas 1961). A second, more questionable, Santa Cruz County report (not shown on the map) concerns one tree on Ben Lomond Mountain. In the Santa Lucia Mountains, Roxana S. Ferris found an apparently native tree in upper San Antonio Canyon. Thus, the south Coast Ranges may have some relict native trees but no significant populations.

The Sierra Nevada distribution stops in northern Kern County near Basket Peak (Twisselmann 1967). Pacific dogwood seems to cross the Sierra Nevada-Cascade crest only in the Pit River region. Some populations appear in the Mixed Conifer Forest of eastern Shasta County, and a few trees make it into Modoc County.

In southern California Pacific dogwood reappears in a few scattered localities in the San Gabriel (Cascade Canyon), San Bernardino, San Jacinto (Dark Canyon), and Cuyamaca Mountains and on Palomar Mountain (Munz 1935).

Other references: Behr 1896, Hall and Hall 1912, Powell 1968, Roof 1959, Stebbins 1968, True 1970.

## *Cupressus* cypresses

**(Cupressaceae Cypress Family)**

As a genus the cypresses are widely distributed in the Northern Hemisphere. Most of the individual species, however, have relatively small ranges. Altogether some 25 species are now recognized. Fifteen cypresses are found in North America, with 10 species growing in California. Of these, eight are endemic to the State, and the other two are basically Californian species. The term "cedar," commonly used in California place names, often refers to a cypress locality.

**Cupressus abramsiana** C. B. Wolf (*C. goveniana* var. *abramsiana* [C. B. Wolf] Little)
*Santa Cruz cypress* *Map 19*

This cypress is confined to four populations in the Santa Cruz Mountains. Wolf (1948) discussed the Bonny Doon and Eagle Rock groves. The Butano Ridge stand, which Wolf looked for but could not find, was relocated in 1949 (McMillan 1952). The VTM survey mapped a fourth stand near Boulder Creek which Thomas (1961) called the Brackenbrae grove. These cypress populations all grow in sterile, sandy, chaparral habitats within a Redwood-Mixed Evergreen Forest mosaic.

The southernmost grove, along Martin Road near Bonny Doon, is probably the best known stand. These cypresses, at 1,600 feet elevation, associate with knobcone pine on sandstone outcrops and with ponderosa pine on deeper soils. Seven miles north, near Eagle Rock lookout, is the smallest grove. This stand numbers less than a hundred trees. At 2,500 feet, it is the highest-elevation grove. The larger Brackenbrae population is 3 miles east of Eagle Rock. It lies on the east side of Boulder Creek canyon around the 1,000-foot level. The cypress trees are scattered within knobcone pine thickets. The northernmost stand is 7 miles northwest of Eagle Rock on the south side of Butano Ridge.

Wolf (1948) considered Santa Cruz cypress as intermediate between the rare, coastal Gowen cypress and the widespread, more interior, serpentine-soil Sargent cypress. McMillan (1956) also discussed some of the intermediate features of Santa Cruz cypress. Little (1970, 1971) recognized Santa Cruz cypress as a variety of Gowen cypress. All four of these variable Santa Cruz cypress populations should be restudied in relation to Gowen and Sargent cypresses. In a geographic sense the Santa Cruz cypress can be viewed as a non-serpentine form of Sargent cypress that survives on sandy soils in the Santa Cruz Mountains. There are serpentine outcrops in the Santa Cruz Mountains, but they have no cypresses.

Other references: Zavarin, Lawrence, and Thomas 1971.

**Cupressus bakeri** Jeps. (including ssp. *matthewsii* C. B. Wolf, Siskiyou Cypress)
*Baker cypress, Modoc cypress* *Map 20*

The southern outposts of Baker cypress are in Plumas County. In 1924, H. F. Wilcox collected specimens near Wheeler Peak (Wagener and Quick 1963). This 3-acre grove lies at 6,500 feet. Five miles to the north near Mud Lake is a larger stand that reaches up to 6,900 feet within the Red Fir Forest. These two stands are the highest-elevation localities of any California cypresses.

Separated from Mud Lake by a gap of more than 60 miles of Sierra Nevada-Cascade terrain is a series of groves in the Burney Springs-Cypress Camp region of Shasta County. Here the cypresses are scattered in a huge brushfield within the Mixed Conifer Forest at elevations of 4,500 to 5,000 feet. An outlying colony of this population on the "North Fork of South Fork of Cow Creek" (Sudworth 1908) was clearly described in a letter from J. C. LaPlant to Sudworth, but it seems to be extinct now (Griffin and Stone 1967).

The largest Baker cypress population sprawls over some 7,000 acres of recent basalt near Timbered Crater (Stone 1965). This stand, near the corner of Modoc, Shasta, and Siskiyou Counties, ranges in elevation from 3,500 to 4,000 feet. It was discovered by Milo S. Baker in 1898. In 1909, Jepson described Baker cypress as a new species from Baker's specimen. Previously Baker cypress had been confused with the rather unrelated MacNab cypress.

A 55-mile gap separates the Timbered Crater cypresses from the next population, on the north slope of Goosenest Mountain at about 5,500 feet (Wolf 1948). About 40 miles farther north in the Cascades, near Prospect, Oregon, is the extreme northern limit of Baker cypress (Little 1970).

Two groups of cypress populations are scattered across the Siskiyou Mountains—one in the Seiad Creek region of California and the second in the Miller Lake-Steve Peak area of Oregon (Wolf 1948). The VTM survey also mapped Baker cypress on the East Fork of Elk Creek, southeast of Happy Camp.

The Sierra Nevada-Cascade groves are on various types of basic igneous rock. In contrast, the cypresses in the Siskiyou Mountains tend to grow on or near serpentine soils.

Wolf segregated the groves in the Siskiyou Mountains and the Goosenest Mountain stand as ssp. *matthewsii*. Since Wolf did not know about the Prospect, Elk Creek, or Plumas County populations, they did not enter into the subspecies consideration. Perhaps the whole subspecies problem should be reviewed.

Other references: Sudworth (n/d).

**Cupressus forbesii** Jeps. (*C. guadalupensis* var. *forbesii* [Jepson] Little)
*Tecate cypress* *Map 21*

Tecate cypress was probably collected in 1872 by James G. Cooper in the Santa Ana Mountains of Orange County (Wolf 1948). This cypress was known from the San Ysidro Mountains of San Diego County in 1880. At various times this taxon was called Gowen cypress, Guadalupe cypress, Monterey cypress, and Sargent cypress. In 1907 Charles N. Forbes brought the problem to Jepson's attention, and Jepson described Tecate cypress as a new species (Jepson 1922). Little (1970, 1971) recognized Tecate cypress as a variety of *Cupressus guadalupensis*.

Wolf's (1948) discussion of the range of Tecate cypress is still essentially complete. The VTM survey provided more detail on areas of cypress dominance, but no new population centers have been found.

The bulk of the California distribution lies on the slopes of Otay Mountain. The cypress is common in the chaparral above the 2,000-foot level, and stragglers are found as low as 1,000 feet elevation. This stand continues across the border into Baja California. Five miles to the east are additional colonies in the Tecate Peak-Potrero Creek area. The Tecate Peak trees also range across the Mexican border.

Some 17 miles north of Potrero Creek near the Guatay Campground is a smaller population of Tecate cypress. It is scattered in chaparral around the 4,000-foot level.

The northernmost grove, in the Santa Ana Mountains, is isolated from the San Diego stands by more than 100 miles. It is scattered on the northwest slopes of Sierra Peak, with a few individuals across the Santa Ana River. Most of this stand has burned twice since 1950 but has reproduced well.

Several disjunct groves extend the range of this cypress about 150 miles south of the San Diego County stands into Baja California (Little 1971).

**Cupressus goveniana** Gord.
*Gowen cypress* *Map 22*

Gowen cypress is restricted to two populations on the Monterey Peninsula. The larger and better known grove is in Del Monte Forest, between Congress Road and the Pacific Grove-Carmel Highway. This stand is often called the Huckleberry Hill grove. It was discovered by Karl T. Hartweg in 1847.

The cypresses grow on late Pleistocene beach terraces with partially podzolized soils. The Gowen cypress shares this sterile, acid, poorly drained habitat with bishop pine and a number of disjunct or endemic shrubs and herbs. Deeper, more fertile soils surrounding the Gowen cypress grove support Monterey pine forest. The Huckleberry Hill cypress grove lies 2 miles inland from the Monterey cypress stand at Point Cypress.

The other Gowen cypress grove is about 5 miles to the south, near Gibson Creek. This grove is within the Point Lobos State Reserve, but is isolated by 1 mile from the Point Lobos Monterey cypresses. The Gibson Creek cypresses are again surrounded by Monterey pine forest, but no bishop pine is associated with them. On some maps this slope above Gibson Creek is also, unfortunately, labeled "Huckleberry Hill."

Gowen cypress is closely related to Mendocino cypress. The whole ecological situation at Huckleberry Hill is reminiscent of the Mendocino cypress pygmy forest barrens on podzol soils near Fort Bragg (Jenny, Arkley, and Schultz 1969). Gowen cypresses grow less vigorously than Mendocino cypresses and form shorter, broader crowns—even on fertile soils. The tallest Gowen cypress that James R. Griffin could find in 1970 at Huckleberry Hill was only 40 feet in height.

Other references: Seeman 1970, Zavarin, Lawrence, and Thomas 1971.

**Cupressus macnabiana** A. Murr.
*MacNab cypress* *Map 23*

MacNab cypress is one of the more common California cypresses. It is widely scattered on relatively poor soils in the Foothill Woodland and Chaparral of northern California. Some populations, composed of only a few trees, are separated by scores of miles from the nearest cypress, but other populations form the dominant cover over thousands of acres. MacNab cypress is often shrubby, particularly in frequently burned habitats. However, in 1965, James R. Griffin found one old-growth MacNab cypress near Round Mountain, Shasta County, that was 55 feet tall and 26 inches in diameter. Paul J. Zinke in 1949 noticed some MacNab cypresses about 60 feet tall in southeastern Mendocino County.

The southern limit for MacNab cypress in the north Coast Ranges is Hooker Canyon (Cavedale Road) in southeastern Sonoma County. In 1905, G. Syme wrote to Sudworth describing two additional groves in the Hooker Canyon vicinity: one 4 miles north and the other 2 miles southeast. We

do not know the current status of Syme's Sonoma County localities.

In the north Coast Ranges MacNab cypress is locally abundant. There it is usually found on soils derived from serpentinized, ultrabasic rocks. It is sometimes associated with Sargent cypress. When these two species grow together, MacNab cypress tends to be the shrubbier species and grows more often on the upper slopes. The westernmost stand was mapped by the SV survey on Red Mountain, northwestern Mendocino County. Apparently a few MacNab cypresses occur there within an extensive Sargent cypress population. Our vegetation type information from northern Napa County is scanty, and additional MacNab cypress groves may well be present there.

The Shasta and Tehama County stands were recently described in detail (Griffin and Stone 1967). Since that review two additional colonies have been located in Shasta County. In 1967, James R. Griffin found a small grove between the Round Mountain and Montgomery Creek populations. E. Bruce Barron located a grove several miles east of the Ash Creek population. The best known Shasta County stand was destroyed by the construction of Whiskeytown Lake.

There still seems to be a 55-mile gap between the scattered Nevada County cypresses and the Amador County grove near River Pines (the Aukum stand of Wolf [1948]). Willis W. Wagener told Munz (1968) of another Amador County grove east of Amador City. Chester O. Stone has been unable to locate this grove in the field.

In the Sierra Nevada-Cascade foothills, MacNab cypress grows on a variety of rock types—greenstone, gabbro, basalt, and conglomerates (Griffin and Stone 1967). The River Pines, Grass Valley-Nevada City, and Magalia stands are on serpentine.

MacNab and Sargent cypresses are the only California cypresses whose distributions overlap. Wolf (1948) discounted all suggestions of hybridization between them, and in many places where they meet there are no intermediates. But field observations increasingly suggest some hybridization, particularly in northern Napa County.

Other references: Sudworth (n/d), True 1970.
Personal correspondence: E. Bruce Barron, Jan. 12, 1970, Chester O. Stone, Dec. 11, 1969.

**Cupressus macrocarpa** Hartw.
*Monterey cypress* *Map 24*

Monterey cypress is restricted to two populations on and near the Monterey Peninsula. Both groves are on the immediate seacoast. Cypresses on the granitic headlands have gnarled, picturesque form, while individuals in more sheltered spots are large, broad-crowned trees.

The larger population is scattered along the Seventeen Mile Drive in Del Monte Forest between Point Cypress and Pescadero Point. Greene (1929) gave a detailed account of this stand before the start of much golf course and residential development in the area. At that time, the inland edge of the cypress grove was being crowded out by the more aggressive Monterey pine forest.

Three miles south of Pescadero Point, across Carmel Bay, is the second Monterey cypress population. It is within, and the main reason for the establishment of, the Point Lobos State Reserve.

Inland from both Monterey cypress populations are Gowen cypress groves (see section on Gowen cypress). Although Monterey and Gowen cypresses belong to the same group of related coastal species, they are relatively distinct (Zavarin, Lawrence, and Thomas 1971). There has never been any serious attempt to consolidate them into one species. Both were discovered by Karl T. Hartweg. Monterey cypress was found in 1846 a few months before Gowen cypress. Why some of the earlier botanical explorers who visited the Monterey area did not find these cypresses is not clear.

Monterey cypress has been extensively planted along the California coastline. Some of the old plantings are becoming naturalized (Hoover 1970, Howell 1970). A few could easily be mistaken for natural populations in the future.

**Cupressus nevadensis** Abrams (*C. arizonica* var. *nevadensis* [Abrams] Little)
*Piute cypress* *Map 25*

Piute cypress groves are sprinkled along 45 miles of the central Kern River drainage (Twisselmann 1967). The small cypress trees grow in Chaparral and an arid phase of the Foothill Woodland on a variety of soil types. The northernmost grove was discovered in 1969 by Robert Luthey 1 mile west of Corral Creek Campground in Tulare County. The largest and best known stand is on the north slope of Bald Eagle Peak, south of Bodfish, between 4,000 and 6,000 feet. Abrams collected the type specimen of this species at this grove in 1915. The southernmost grove was mapped by the VTM survey in Back Canyon near the head of Caliente Creek. Wolf (1948) knew of only three Piute cypress populations. At least six new localities have been found. Perhaps a few additional groves have yet to be discovered.

Piute cypress is clearly related to Arizona cypress, and Little (1966b, 1971) recognized it as a variety of Arizona cypress.

Other references: Twisselmann 1962.
Personal correspondence: Ernest C. Twisselmann, May 10, 1968.

**Cupressus pygmaea** (Lemm.) Sarg. (*C. goveniana* var. *pigmaea* Lemm.)
*Mendocino cypress* *Map 26*

The bulk of Mendocino cypress distribution lies between Fort Bragg (Virgin Creek) and Albion (Little Salmon Creek). There stunted cypresses grow on an extremely acid, sterile, podzol soil developed on old beach terraces (Jenny, Arkley,

and Schultz 1969). These "pygmy" cypresses are associated with *Pinus contorta* and *P. muricata.* Fertile soils surrounding the cypress barrens support productive Redwood Forest. This species has been called pygmy cypress, but this name is misleading. "Pygmy" cypresses which grow on better soils form large trees–well over 100 feet tall.

Several Mendocino cypress populations are scattered south of Point Arena (Galloway Creek, Slick Rock Creek, Roseman Creek). Wolf (1948) referred to these as the "Anchor Bay" locality. The soil sterility in these spots is not as extreme as in the Fort Bragg barrens (McMillan 1956). These cypresses are again associated with *Pinus muricata.*

The southernmost grove was recently found and mapped by the SV survey in Sonoma County (Powell 1968). It is in Miller Gulch south of Plantation. This Mendocino cypress grove, which is on a partially podzolized soil, is only 9 miles west of "The Cedars," a large Sargent cypress population on serpentine.

John G. Lemmon described Mendocino cypress in 1895 as a variety of Gowen cypress. Charles S. Sargent described it as a separate species in 1901. Since then there has been much confusion and debate about the taxonomic status of these cypresses. Little (1970, 1971) recognizes Mendocino cypress as a variety of Gowen cypress.

Other references: Zavarin, Lawrence, and Thomas 1971.
Personal correspondence: Ray T. Collette, Jr., Aug. 21, 1970.

**Cupressus sargentii** Jeps.
*Sargent cypress* *Map 27*

Sargent cypress is not at all rare. It is locally abundant in scattered populations along 400 miles of the Coast Ranges. Some of the most extensive stands are in the Eden Valley region of eastern Mendocino County. Almost all Sargent cypresses are restricted to soils derived from serpentine. In the north Coast Range Sargent cypress tends to be concentrated near creeks and lower canyon slopes. In protected spots and on better soils the trees may be 50 to 100 feet tall. At times Sargent cypress forms vast dense shrubby thickets on ridges, as on Cedar Roughs in Napa County.

The northern limit is on Red Mountain north of Cummings in Mendocino County. The southernmost grove is in Chiminea Canyon near Zaca Peak, Santa Barbara County. Compared to the distribution of Gowen or Mendocino cypress, Sargent cypress is a relatively interior species. Mount Tamalpais, Marin County, and Alder Creek, Monterey County, are the most nearly coastal Sargent cypress localities. The most interior trees are on Little Stony Creek in Colusa County. Sargent cypress meets MacNab cypress in a number of places in the north Coast Ranges (see section on MacNab cypress).

When Sargent cypress became known to the botanical community is not certain. Jepson described it as a new species in 1909, but he had seen Sargent cypress on Cedar Mountain in Alameda County as early as 1880. And the name "Cedar Mountain" was already in general use at that time. Sargent cypress has been confused with a number of other California species. It is probably most closely related to Santa Cruz and Gowen cypresses.

Other references: Hardham 1962, Howell 1970, Wolf 1948, Zavarin, Lawrence, and Thomas 1971.

**Cupressus stephensonii** C. B. Wolf (*C. arizonica* var. *stephensonii* [C. B. Wolf] Little)
*Cuyamaca cypress* *Map 28*

Local ranchers knew of cypresses in the King Creek region of Cuyamaca Peak in San Diego County as early as 1900 (Wolf 1948). Later J. Bert Stephenson, the Descanso District Ranger, became interested in these trees and distributed specimens to several herbaria. Wolf described the cypresses as a new species in 1948.

The type locality on upper King Creek is still the only known stand of this species. Thus, this cypress has the most restricted range of any tree in California. Fires which swept the Cuyamaca region in 1950 and 1970 further reduced the size of this single population. The young cypresses are scattered within chaparral at the 4,000-foot level.

Many references to this cypress have been vague about whether the grove was in the Cuyamaca Rancho State Park or in the adjacent Cleveland National Forest. Apparently the species grows in both, with the larger portion of the existent population on the National Forest (Little 1970).

Cuyamaca cypress, like Piute cypress, is closely related to Arizona cypress. Little (1966b) recognized both as varieties of Arizona cypress.

The Cuyamaca cypress grove is only about 6 miles from the Guatay locality of the unrelated Tecate cypress.

## *Fraxinus* ashes

**(Oleaceae Olive Family)**

Tree and shrub ash species number about 65–all in the Northern Hemisphere. Of 16 species in the United States, four extend into California. Two species–*Fraxinus anomala* Torr., growing on several ranges in the Mojave Desert, and *F. dipetala* Hook. & Arn., widely scattered in chaparral habitats from Siskiyou County southward–are not consistently of tree size or form. Neither is mapped. The two species included here, *Fraxinus latifolia* and *F. velutina,* were both classified as subspecies of the eastern *F. pennsylvanicum* by Miller (1955).

**Fraxinus latifolia** Benth.
*Oregon ash* *Map 29*

Oregon ash ranges from British Columbia to southern California in riparian habitats. In southwestern Oregon it is common in swales and swamps. In California, Oregon ash is very conspicuous in the canyons of the Pit and Sacramento Rivers. It was probably a minor component of the pristine riparian forest of the Sacramento Valley. "Ashes" were

noticed on the lower Sacramento, Feather, and Yuba Rivers by early travelers (Thompson 1961).

In the south Coast Ranges, Oregon ash is rare (Thomas 1961). Jepson (1910) reported the Coast Range southern limit as near Gilroy.

South of the Kern River Oregon ash becomes increasingly similar to the closely related *Fraxinus velutina,* and there is no sharp boundary between the two species (Munz and Lauder-milk 1949). Twisselmann (1967) states that most ashes in Kern County are intermediate in one or more characters between Oregon and velvet ash. The large distribution of *Fraxinus latifolia* shown by Little (1971) in southern California is probably not based on typical Oregon ash.

Other references: Howitt and Howell 1964, Rubtzoff 1953, True 1970.
Personal communication: Audrey E. Kursinski (n/d).

**Fraxinus velutina** Torr. (including *F. oregona* var. *glabra* Lingelsh. ex Rehd.)
*velvet ash, Arizona ash* *Map 29*

Velvet ash is a variable species that intergrades with and replaces Oregon ash in southern California (see section on Oregon ash). Some of the localities included in velvet ash here have been called Oregon ash in the older literature—often as var. *glabra.* Munz (1959) refers all of the southern California ashes to *F. velutina* var. *coriacea* (Wats.) Rehd.

The larger portion of velvet ash distribution lies outside California. Velvet ash is scattered in wet places across the deserts into Utah, east to Texas, and south into Mexico.

Other references: Boughey 1968, Clokey 1951, Coville 1893, Jepson 1910, Lewis and Gause 1966, Raven and Thompson 1966, Wolf 1935.
Personal communication: Peter G. Sanchez, Aug. 4, 1970.

## *Juglans* walnuts

**(Juglandaceae Walnut Family)**

Ten to 20 species of walnuts have been described, mostly in the Northern Hemisphere but with some South American species. Six species are native to the United States, and two of these are endemic to California. The closest walnut outside of California is Arizona walnut *(Juglans major* [Torr.] Heller*)* in Arizona (Little 1950).

**Juglans californica** S. Wats.
*southern California black walnut, California walnut* *Map 30*

*Juglans californica* is locally common in the Southern Oak Woodland from the Santa Ynez Mountains eastward to the Santa Ana Mountains. It usually grows below the 2,500-foot level. This walnut tends to be more shrubby in form than *J. hindsii,* but *J. californica* is often massive in size for a "shrub" (Jepson 1910).

*Juglans californica* is clearly native in southeastern Santa Barbara County. Axelrod (1967b) viewed a *J. californica* colony on Jalama Creek in western Santa Barbara County as a natural disjunct locality. One apparently natural disjunct colony occurs to the east of the main population in San Bernardino County near Etiwanda.

This walnut is becoming established well beyond its natural limits. McMinn (1951) mentioned *J. californica* in San Luis Obispo County, but Hoover (1970) did not know of any walnuts native to the county. Munz (1968) implied that *J. californica* was native to Monterey County, but the Arroyo Seco specimen in question is probably not indigenous (Howitt and Howell 1964). A Cuyamaca Peak specimen from San Diego County is also questionable.

Other references: Boughey 1968.
Personal communication: Reid Moran, Oct. 12, 1970.

**Juglans hindsii** Jeps.
*Hinds walnut (California black walnut)* *Map 31*

Few things are certain about the natural distribution of this walnut. One fact is that Richard B. Hinds found walnut scattered along the pristine riparian forest of the lower Sacramento River when he sailed up the river in H.M.S. Sulphur in 1837. There is also evidence that natural populations existed in the Walnut Creek region of Contra Costa County before Spanish settlement. Most of the other traditional localities, such as Mitchell Canyon (Bowerman 1944), Mount Hamilton (Sharsmith 1940), or Atlas Peak and Gordon Valley (Jepson 1917), are based on individual old trees or small groves of trees which were thought to pre-date European settlement. In 1911, Jepson counted 98 annual rings of one tree on Atlas Peak.

The situation is now hopelessly confused, for *J. hindsii* is widely naturalized in central California along the larger creeks and streams. Numerous streams that leave the inner Coast Range foothills in Colusa, Glenn, and Tehama Counties now have stands of large trees that look like natural populations. Yet, these must be relatively recent in origin. Jepson and his colleagues were concerned about the status of *J. hindsii,* and we believe they would have discussed these obvious, easily accessible populations if they had existed as natural-appearing stands in the early 1900's.

Aside from the serious problem of naturalization since Europeans settled in California, there is an older question of Indian influence on walnut distribution. Jepson (1910) observed that some walnut localities coincided with Indian encampments. Jepson and others later emphasized this correlation without adding any facts. Thomsen (1963) studied this problem from a paleobotanical point of view and largely discounted Indian influence on *J. hindsii* distribution.

Other references: Jepson 1892, Jepson (n/d).

## *Juniperus* junipers

**(Cupressaceae Cypress Family)**

From 40 to 60 tree and shrub species of junipers have been described. They are widely scattered in the Northern Hemisphere. One species grows in the Southern Hemisphere as far south as Rhodesia. Thirteen species are native to the United States. Four junipers range into California, but two of these are not consistently tree-like. *Juniperus communis* var. *saxatilis* Pall. is always a low or prostrate shrub. *Juniperus californica* Carr., which we have omitted, is a more marginal case. In habit California juniper is usually shrubby, but occasionally the shrubs are quite large. One California juniper "shrub" in a fire-proof habitat in Shasta County is 32 feet tall and 40 feet broad. Both of these junipers were mapped by Little (1971). Rocky Mountain juniper, *J. scopulorum* Sarg., comes close to the California border in southern Nevada (Fowells 1965), and there are unconfirmed rumors that this species occurs in Modoc County.

**Juniperus occidentalis** Hook.
*western juniper* *Map 32*

Western juniper is a tree of open woodlands, widely distributed in the western United States from southern Washington and western Idaho to southern California (Vasek 1966).

Vasek (1966) recognized two subspecies of western juniper: *occidentalis* and *australis*. Subspecies *occidentalis*, the more northern entity, dominates the Northern Juniper Woodland on the Modoc Plateau. It continues northward on similar relatively low-elevation, volcanic habitats. This form of western juniper is scattered westward across the Cascades into the Scott Valley near Callahan. In the central Klamath River Canyon, western juniper grows as low as 2,000 feet in elevation. East of the Warner Mountains in northwestern Nevada *J. occidentalis* may hybridize with *J. osteosperma* (Vasek 1966).

Subspecies *australis* occurs in higher-elevation habitats, at times approaching 11,000 feet. Along the Sierra Nevada this subspecies is often associated with Jeffrey pine and other subalpine trees on dry, exposed ridges. The northern limit is near Susanville (Vasek 1966). The Sierra Nevada populations extend south to Owens Peak in Kern County (Twisselmann 1967). In west-central Nevada the VTM survey found scattered western junipers on the ridges above the widespread Utah juniper woodland. Disjunct populations of western juniper occur in the San Gabriel and San Bernardino Mountains. There are scattered trees in the Panamint and Inyo Mountains. Two relict individuals, possibly hybrids with Utah juniper, survive in the White Mountains (Vasek 1966).

We have no confirmation of Sudworth's (1908) report of western juniper near Canyon Creek Lakes in the Trinity Alps. Perhaps this report was based on *J. communis*. Jepson did collect western juniper in southeastern Trinity County in 1897 on Soldier Ridge (Vasek 1966). This Trinity County report appears as an excessively large distribution in Fowells (1965) and Little (1971). The report of *J. californica* in Jackson County, Oregon (Little 1953), is probably based on western juniper. The northern limits of *J. californica* are far to the south in Shasta County (Little 1971), but *J. occidentalis* crosses the California state line into Jackson County, Oregon, near Mount Ashland.

Other references: Griffin and Powell 1971, Grinnell and Storer 1924, Howell 1940-42, 1946-49, Lewis and Gause 1966, Raven 1950-53.
Personal correspondence: Peter G. Sanchez, Aug. 4, 1970, Frank C. Vasek, Dec. 1966.

**Juniperus osteosperma** (Torr.) Little
*Utah juniper* *Map 33*

In habit Utah juniper is intermediate; it is larger and more often tree-like than California juniper, but smaller than western juniper. The bulk of Utah juniper's range is outside of California. It spreads across the Great Basin and adjacent regions from southern California northward to southern Montana and eastward to New Mexico (Vasek 1966).

In California it is dominant in the Pinyon-Juniper Woodland of the desert ranges. Little detailed information is available about the distribution of this community. We have even less data on which woodlands contain Utah juniper.

Disjunct populations of Utah juniper occur in the San Bernardino Mountains (Vasek 1966). There Utah juniper grows from 4,500 to 6,000 feet, between the desert California juniper and the montane western juniper. Another disjunct stand lies within a California juniper woodland north of the San Gabriel Mountains just west of Phelan.

The VTM survey mapped areas in which Utah juniper was dominant in west-central Nevada. This population crosses the State line and is scattered along the eastern fringes of Sierra Valley. There is some hybridization between Utah and western juniper in this region northwest of Reno. Utah juniper populations also approach California in the northwestern corner of Nevada. Milligan (1968) found a few Utah junipers near Jess Valley, Modoc County, in an area that is predominantly covered with western juniper.

Other references: Clokey 1951, Lloyd and Mitchell 1966, Weislander and Jensen 1945, Wells and Berger 1967.
Personal correspondence: Peter G. Sanchez, Aug. 4, 1970, Philip V. Wells, Sept. 23, 1970, Frank C. Vasek, Dec. 1966.

## *Libocedrus (Calocedrus)* incense-cedars

**(Cupressaceae Cypress Family)**

This genus has about 12 species in both Northern and Southern Hemispheres. The three species in the Northern Hemisphere—in China, Taiwan, and North America—are some-

times separated into the genus *Calocedrus.* This genus is receiving increasing, but far from unanimous, usage in California (Munz 1968).

**Libocedrus decurrens** Torr.
*incense-cedar* *Map 34*

Incense-cedar is largely an Oregon and California species (Fowells 1965). In Oregon it is common in the Mixed Conifer Forest of the eastern Siskiyou and western Cascade Mountains (Franklin and Dyrness 1969). Its northern limit is near Mount Hood. Several stands in Baja California mark the southern limit.

Incense-cedar is sprinkled through the relict Mixed Conifer Forest of southern California, from the Laguna Mountains north to the Tehachapi Mountains and Sierra Madre. The VTM survey mapped several small colonies in the San Emigdio Range (see also Twisselmann 1967). In northern Santa Barbara County the VTM survey found spots where this species had been recently eliminated by fire—snags still standing but no seedlings or saplings to be found.

In the Santa Lucia Mountains there are small stands mostly near streams. An interesting population survives in the arid region to the east of the Santa Lucias in the Clear Creek-San Benito Mountain region. In this highly serpentinized, ultrabasic-rock habitat, incense-cedars are not confined to canyon bottoms but even appear on the most exposed slopes. Scattered stumps in the chaparral and on bald talus slopes suggest that incense-cedar was more widespread before intensive mining activity in this region.

In the Sierra Nevada, from the Greenhorn Mountains northward (Twisselmann 1967), incense-cedar is an important part of the Mixed Conifer Forest over a broad elevational range. At lower elevations it is at times more abundant than the associated pines. Incense-cedar is locally common east of the Sierra Nevada-Cascade crest in the "eastside-pine" phase of the Mixed Conifer Forest. A few colonies appear in the northern Warner Mountains.

In the north Coast Ranges and western portion of the Klamath Ranges incense-cedar tends to be restricted to serpentine soils. Good examples of such serpentine colonies can be seen near Boonville, Mendocino County, and west of Miranda, Humboldt County. To the east, particularly at higher elevations, incense-cedar gradually becomes less restricted to specialized soil situations and is a regular component of the Mixed Conifer Forest.

A few old plantations might be mistaken for natural stands, including those at Kinevan Canyon and Zaca Lake in Santa Barbara County (Van Rensselaer 1948), and on Copernicus Peak in Santa Clara County (Sharsmith 1945).

Other references: Applegate 1938, Brewer (n/d), Grinnell 1908, Klyver 1931, Lewis and Gause 1966, Meyer 1931.

## *Lithocarpus* tanoaks

**(Fagaceae Beech Family)**

Tanoak is largely an Asian genus. More than 100 tree and shrub species are scattered from Japan to Indonesia. Only one species grows in North America, mostly in California.

**Lithocarpus densiflorus** (Hook. & Arn.) Rehd. (including the shrubby var. *echinoides* [R. Br.] Abrams)
*tanoak* *Map 35*

The northern limit of tanoak is near the Umpqua River in southwestern Oregon (Fowells 1965). In both Oregon and California, tanoak is an important part of the Mixed Evergreen Forest. In California it is also an understory species in portions of the Redwood and Douglas-fir Forests. Throughout its range, tanoak frequently associates with madrone.

In San Luis Obispo and Santa Barbara Counties, tanoak is restricted to the most mesic portions of the southern phase of the Mixed Evergreen Forest. Some of these south Coast Range populations are shrubby (Hoover 1970). The VTM survey mapped tanoaks near the eastern end of the Santa Ynez Mountains in Ventura County. Sudworth's (1908) report of tanoak on Mount Pinos, which is perpetuated by Fowells (1965) and Little (1971), is probably in error. Axelrod (1967b) reported tanoak in the Topatopa Mountains of Ventura County, but this locality did not appear in the VTM records.

In parts of Shasta as well as adjacent Trinity and Siskiyou Counties, tanoak is common in a shrubby form on many rocky, exposed ridges, but in protected spots trees up to 50 feet tall can be found. Although Cooke (1940, 1941) excluded tanoak from the Mount Shasta flora, it does grow in the brushfields south of Mount Shasta City.

South of Clover Creek, Shasta County, there seems to be a 50-mile gap in tanoak distribution. Then from Butte County to El Dorado County tanoak is again locally abundant in the middle-elevation Mixed Conifer Forest. Most of these tanoaks are trees but not as large as the coastal tanoaks.

Scattered occurrences of tanoak, usually shrubby in form, are present in Tuolumne and Mariposa Counties. The southernmost record we could find was Jepson's (1910) collection at Devils Gulch in Mariposa County.

Other references: Griffin and Powell 1971, Havlik 1970, Hemphill 1962, McMinn 1951, Oberlander 1953, Roy 1957.

## *Lyonothamnus* Lyontree

**(Roseaceae Rose Family)**

This genus has no close relatives in the Rose Family. The fossil record suggests that *Lyonothamnus* trees grew in many parts of the western United States in the Tertiary period (Banwar 1970). Now this relict genus only has one species, which is confined to parts of the southern California islands.

**Lyonothamnus floribundus** A. Gray
*Catalina-ironwood, Lyontree* *Map 36*

Catalina-ironwood is restricted to four of the southern California islands. A tree form with entire leaves (ssp. *floribundus*) is found only on Santa Catalina Island (Raven 1963, Thorne 1967). A shrubby form with pinnate leaves (ssp. *asplenifolius* [Greene] Raven) grows on Santa Cruz, Santa Rosa, and San Clemente Islands. Older references suggest that both forms grow on Santa Catalina Island, but Raven (1963) and Thorne (1967) doubt that ssp. *asplenifolius* grows there.

William S. Lyon made the type collection on Santa Catalina Island in 1884, but Jepson (1910) suggests that earlier collections had been sent to Europe.

## *Picea* spruces

**(Pinaceae Pine Family)**

About 35 to 40 species of spruces have been described. All are trees and all are native to the Northern Hemisphere. Eight species grow naturally in North America, three ranging into California.

**Picea breweriana** S. Wats.
*Brewer spruce, weeping spruce* *Map 37*

Compared to most North American spruces, Brewer spruce has a restricted range. Yet it is not as rare as the literature suggests. It is far more common, for example, than either of the spruces native to northern Mexico.

Populations of Brewer spruce are sprinkled on higher ridges across 140 miles of the Klamath Mountains. The impression of rarity is due partly to the steep terrain and difficult access of Brewer spruce habitats. The northern outpost, according to Matthews (1966), is on Iron Mountain, Oregon, near the 4,000-foot level. Brewer spruce is locally common in the western Siskiyous in Oregon and both eastern and western Siskiyous in California. It usually occurs above the 5,000-foot level, but extends as low as 3,300 feet on Knopti Creek in Del Norte County (Sawyer and Thornburgh 1969). Brewer spruce seldom grows in pure stands, but it is a minor component in a variety of communities.

Dennis Anderson collected Brewer spruce at East Weaver Lake in Trinity County. This is probably the southern limit for the species.

Disjunct eastern colonies of spruce appear in Castle Crags (Haddock 1938) and the Castle Lake region. This region is not far from the place where Josiah D. Whitney found a single spruce in 1862. He collected a specimen on a volcanic cone north of Strawberry Valley, probably Black Butte. Whitney gave the specimen to Brewer, whose journal indicates that it was the only example seen of this remarkably weeping tree. Brewer spruce was formally described in 1885 from a specimen collected by Thomas J. Howell in the Siskiyou Mountains.

Other references: Brewer (n/d), Sawyer and Thornburgh 1970, Tracy (n/d).
Personal correspondence: Dennis Anderson, June 13, 1970.

**Picea engelmannii** Parry
*Engelmann spruce* *Map 38*

This spruce is widely distributed in the higher mountains of western North America from central British Columbia to southern Arizona (Fowells 1965). In California, however, it is rare. Engelmann spruce is clearly related to the widespread eastern white spruce *(P. glauca* [Moench] Voss*)*. Both spruces have been placed in the same species by some botanists.

In the Oregon Cascades Engelmann spruce is a minor component of the "*Tsuga mertensiana* zone" (Franklin and Dyrness 1969). Farther south, in the Siskiyou Mountains of Oregon, Jepson (1909) found a disjunct stand of Engelmann spruce in 1906. This stand, on the East Fork of Ashland Creek, is near the California border, and Jepson anticipated finding it across the state line.

In 1921 W. H. Snell, a forester for the Southern Pacific Company, finally found this spruce in California—but some 90 miles southeast of Mount Ashland. This spruce stand is scattered in a strip along Clark Creek for almost 2 miles. It is within the Mixed Conifer Forest at elevations from 4,000 to 4,500 feet.

A much larger spruce population was later found in the Russian Peak region of Siskiyou County. On the east slope of the mountain, spruce is concentrated in the valley bottoms of Horse Range, Duck Lake, and Sugar Creeks. Individual trees occur along Sugar Creek as low as 3,300 feet. On the western slope the spruce grows mainly along Music Creek and Blakes Fork of South Russian Creek. In several spots on Russian Peak individual Brewer spruces are scattered down into the Engelmann spruce groves. The upper limit of Engelmann spruce is about 6,500 feet. Engelmann spruce groves begin in the Red Fir Forest and extend down into the Mixed Conifer Forest.

Around 1908 Laura F. McDermott, a student of Jepson, collected specimens of what she called Engelmann spruce on Mount Rose, Nevada (Jepson 1909). The circumstances of this collection are now confused. A University of California janitor seems to have lost the cones of this collection before Jepson saw them. The foliage specimens cannot be located, although mountain hemlock specimens collected by McDermott on the same trip are in the Jepson Herbarium.

Other references: Jepson (n/d), Sawyer and Thornburgh 1969, 1970, Sudworth (n/d).

**Picea sitchensis** (Bong.) Carr.
*Sitka spruce* *Map 39*

Sitka spruce is common in a coastal strip from southern Alaska to northern California (Fowells 1965). It seldom grows more than 30 miles inland.

The main distribution in California stops in Humboldt County south of Ferndale. Farther south, scattered Sitka

spruce stands reappear in Mendocino County between Fort Bragg and Big River (Jepson 1910). Three trees in Russian Gulch are the southern limits of the species, according to John Olmsted.

Sitka spruce is an important constituent of the North Coastal Coniferous Forest. It is particularly common in boggy areas around the mouths of the larger rivers. Red alder is a frequent associate.

Personal communication: John Olmsted (n/d).

## *Pinus* pines

**(Pinaceae Pine Family)**

The pines are a large and diverse genus of trees, with about 94 species in the Northern Hemisphere. One species crosses the Equator in Sumatra. Fifty-nine pines grow in North America. *Pinus* is better represented in California than any other genus of trees, with 19 species. Three pines are strictly endemic to the State. Another eight are basically California species, but range into Baja California, Nevada, or Oregon.

**Pinus albicaulis** Engelm.
*whitebark pine* *Map 40*

This subalpine species ranges from central British Columbia south to central California and east to Wyoming (Critchfield and Little 1966). Through much of its range whitebark pine is characteristic of timberline, where it often forms dense thickets.

In California, the bulk of whitebark pine's distribution is along the crest of the Sierra Nevada, in areas where we had very limited vegetation type data. In the southern Sierra Nevada this pine sometimes grows as high as 12,000 feet (Howell 1940-42). North of the Lake Tahoe-Mount Rose area the mountains are no longer high enough to support extensive whitebark pine stands. The VTM survey found a few trees on Peavine Peak, Nevada, northwest of Reno, and there is another outlier in the Virginia Range, Nevada. Whitebark pine grows on Castle Peak in Nevada County (Howell 1943). An old report of this pine on Mount Fillmore in Plumas County seems to be based on *Pinus monticola.* We have no confirmation of Sudworth's (1908) reports of this pine on Spanish Peak or Mount Pleasant in Plumas County.

In the southern Cascades, whitebark pine is common on the high ridges of Lassen Volcanic National Park. It grows on Magee Peak in Shasta County. Scattered stands appear on the highest peaks northeast of Mount Shasta. It encircles Mount Shasta, forming a true timberline (Cooke 1940). The VTM survey found a couple of trees on Black Butte just west of Mount Shasta near the 6,000-foot level. Whitebark pine is common on the higher portions of the Warner Mountains, but we have no type-map information.

In the Klamath Ranges the species is rare—confirmed localities are Mount Eddy, Thompson Peak, Russian Peak, and the Marble Mountains. A few trees occur just north of the California line on Mount Ashland, Oregon (Waring 1969), but the Donomore Meadows locality shown on the maps in Critchfield and Little (1966) and Little (1971) just inside California is probably in error. The Humboldt County locality in Little (1971) must be improperly plotted.

Other references: Billings 1954, Klyver 1931, Lewis 1966, Little 1966a, Maciolek and Tunzi 1968, Major and Bamberg 1963, Peirson 1938, Raven 1950-53, Rockwell and Stocking 1969, Sawyer and Thornburgh 1969, 1970.
Personal correspondence: G. Ledyard Stebbins, Jr., Aug. 6, 1970.

**Pinus aristata** Engelm.
*bristlecone pine* *Map 41*

The eastern race of bristlecone pine is common in subalpine forests in parts of Colorado and New Mexico (Bailey 1970). The western race, which Bailey (1970) has named *Pinus longaeva,* extends westward from Utah across the high desert ranges, and just enters the eastern portion of California. In California these ancient pines are common only in the White Mountains at elevations of 9,500 to 11,500 feet, where they dominate the Bristlecone Pine Forest. Even in the White Mountains bristlecone pine is well developed only on dolomitic soils (Wright and Mooney 1965). Scattered populations also appear in the Inyo and Last Chance Mountains, and on Telescope Peak in the Panamint Range. Bristlecone pine was more widely distributed in this region in the recent past (Mehringer and Ferguson 1969).

Other references: Clokey 1951, Little 1956, Lloyd and Mitchell 1966, Powell 1963.

**Pinus attenuata** Lemm.
*knobcone pine* *Map 42*

This closed-cone pine reaches its northern limits in the Oregon Cascades, near the North Fork of the Middle Fork of the Willamette River (Critchfield and Little 1966). To the southwest it is abundant in the western Siskiyou Mountains of Oregon. Knobcone pine is widely scattered across the Klamath Mountains in California, where it grows over a wide range of elevations within several forest types—usually on rocky slopes. Much of the northwestern distribution is on serpentine soils.

Knobcone pine ranges eastward over the Cascade Range. On Mount Shasta it approaches 6,000 feet at its upper limits. The pine extends into southwestern Modoc County where we have little vegetation type data. Newcomb (1962) mentioned an old report of knobcone pine in north-central Modoc County, but we could not confirm this locality. Applegate (1938) found one isolated tree on Hippo Butte in the Lava Beds National Monument.

The SV survey mapped two disjunct populations in eastern

Tehama County: several small colonies on Inskip Butte and larger stands in Darling Ravine. The discontinuous Sierra Nevada distribution reaches its southern limits in Yosemite National Park (Cole 1963, Jepson 1910). Munz (1968) mentioned a knobcone pine collection in Tulare County, but there seems to be little evidence for a native population in this region (Rockwell and Stocking 1969). Munz's report may be based on knobcone pine planted along the Mineral King road.

In the Coast Ranges, this species forms dense stands on poor soils within the chaparral zone. Lake County has extensive areas of such frequently burned knobcone pine thickets. Our Napa County data are incomplete, and additional stands may well be found there. Native stands are absent from Marin County, but knobcone pine was planted on Mount Tamalpais near Laurel Dell. This plantation burned in 1945 but successfully regenerated (Howell 1970). Near Swanton in the Santa Cruz Mountains the distribution of knobcone pine meets that of the closely related Monterey pine, and a few natural hybrids have been found. It was in the Santa Cruz Mountains that Karl T. Hartweg first collected knobcone pine in 1845. Coleman's (1905) mention of knobcone pine on the Monterey Peninsula must be in error. Sudworth (1908) and Jepson (1923) repeated this error without any confirming evidence. In San Luis Obispo County the best-known population (Hoover 1970) lies southeast of Cuesta Pass. The VTM survey also found a tree 10 miles to the northwest and a tiny colony east of the Salinas River near Pilitas Creek.

In southern California is a group of populations in the San Bernardino Mountains. A small population grows on Pleasants Peak in the Santa Ana Mountains. A stand near Ensenada, Baja California, some 150 miles away, is the southern limit for the species.

Our map corrects several errors in the knobcone pine maps of Critchfield and Little (1966) and Little (1971). We cannot re-establish the basis for the Butte and Plumas County localities. The stand in southwestern Mendocino County is based on an SV survey error. A re-examination of the VTM data for Santa Barbara County suggests that the mapped locality was not native. Van Rensselaer (1948) cautioned that knobcone pine was planted in several spots in Santa Barbara County.

Axelrod (1967a) suggested that knobcone pine grew in the Purisima Hills of western Santa Barbara County within recent decades. The specimens Axelrod cited lend little support to his suggestion. Loye Miller's 1925 knobcone collection (UCLA 6176, 6177) is labeled "near Lompoc" and implies nothing about a native tree on Purisima Ridge. Carl C. Epling's 1940 cone collections (sample B) and Carl B. Wolf's 1931 specimen (RSABG 2313) both came from Purisima Ridge, but appear to be bishop pine—not knobcone pine. In agreement with Newcomb (1962), we find no conclusive evidence for native stands in Santa Barbara County.

Other references: Bowerman 1944, Constance 1935, Lewis 1966, Stebbins 1968.

**Pinus balfouriana** Grev. & Balf.
*foxtail pine* *Map 43*

Several California plant species have disjunct distributions in the Klamath Mountains and the southern Sierra Nevada, 300 to 400 miles apart. Foxtail pine is a good illustration of this pattern. The northern distribution includes several scattered stands in the Marble Mountains (Lewis 1966). Sawyer and Thornburgh (1969) found a stand near High Lake on Russian Peak. Additional stands grow on Mount Eddy and the Scott Mountains, the bulk of the northern trees being in the Trinity Alps. Outliers of the northern group occur on North and South Yolla Bolly.

The Sierra Nevada stands center around the upper South Fork of the Kern River drainage. There foxtail pine is the dominant tree of the extensive Subalpine Forest (Twisselmann 1971). Foxtail pines on the east side of the Sierra Nevada are only 20 miles from the closely related bristlecone pine in the Inyo Mountains. Sudworth's (1908) report of foxtail pine on the Kings-San Joaquin River divide has not been confirmed. The southern known limit of the Sierra Nevada populations is a stand on Sirretta Peak, first encountered by Victor Aubin in 1966. Specimens from this stand were first collected by Tony Gasbarro of the Forest Service in June, 1967.

Other references: Harvey and Mastrogiuseppe 1971, Little 1966a, Mastrogiuseppe [1968], Rockwell and Stocking 1969, Sawyer and Thornburgh 1970, Twisselmann [1971].
Personal correspondence: Ronald J. Mastrogiuseppe, Feb. 17, 1969, John Thomas Howell, Feb. 29, 1972.

**Pinus contorta** Dougl. (including *P. murrayana* Grev. & Balf.)
*lodgepole pine, shore pine* *Map 44*

Lodgepole pine extends from the central Yukon down to Baja California and east to South Dakota (Critchfield and Little 1966). Within this area it grows at a wider range of elevations—sea level to 12,000 feet—than any other pine. Several names have been applied to regional forms of this variable species. Critchfield (1957) recognized four subspecies. Three of them grow in California, and one grows only in California.

The Sierra Nevada-Cascade form of lodgepole pine is ssp. *murrayana*. This is the "tamarack" of California mountain place names. It is scattered westward in typical form to the Marble Mountains (Lewis 1966) and the eastern Siskiyous (Waring 1969). John Jeffrey first collected this subspecies in the Siskiyou Mountains in 1852. To the east, lodgepole pine is more common on the Modoc Plateau than shown on our map. It continues south in the Sierra Nevada as part of the Red Fir, Lodgepole Pine, and Subalpine Forests. On the Kern Plateau lodgepole pine is common around meadows in a Jeffrey pine phase of the Mixed Conifer Forest. Disjunct colonies grow in the White Mountains (Critchfield 1957, Powell 1963, Lloyd and Mitchell 1966); the largest is a nearly pure stand of about

200 acres near Cabin Creek at an elevation of 10,200 to 10,500 feet. Larger populations appear on the San Gabriel, San Bernardino, and San Jacinto Mountains in southern California.

Shore pine, ssp. *contorta,* is sprinkled along the coastal bluffs and sand dunes as far south as Manchester, Mendocino County. A highly localized closed-cone form, ssp. *bolanderi,* grows on the podzol soils near Fort Bragg in association with Mendocino cypress and bishop pine (Jenny, Arkley, and Schultz 1969, McMillan 1956). An unnamed closed-cone race grows on the low mountains of central Del Norte County.

Other references: Applegate 1938, Grinnell 1908, Lewis and Gause 1966, Maciolek and Tunzi 1968, McKeever 1961, Sawyer and Thornburgh 1969, Twisselmann 1967, 1971.
Personal communication: Richard May (n/d).

**Pinus coulteri** D. Don
*Coulter pine* *Map 45*

Since the VTM survey covered almost the entire California range of Coulter pine, our map is relatively complete. Only one significant correction to the Critchfield and Little (1966) and Little (1971) versions of this map was noted. We find that the Ventura County localities for Coulter pine were erroneously compiled. The original VTM survey records and current opinions of Clifton F. Smith and Ernest C. Twisselmann suggest that Coulter pine does not grow there. We can now find no evidence for native Coulter pine in Ventura County—a rather strange absence since so much habitat there seems appropriate.

Several colonies on sandy soils near the Nortonville-Somersville area of Contra Costa County form the extreme northern limit for Coulter pine. It covers a larger area on Mount Diablo about 4 miles to the southwest (Bowerman 1944). Rumors of Coulter pine farther north seem to be based on planted Coulter pine in Colusa County and on native Digger pine in Tehama County.

Coulter pine is prominent in the southern California Mixed Conifer Forest, particularly on the lower edges where repeated fires are converting the forest to chaparral. In a number of areas Coulter pine's distribution overlaps that of Jeffrey pine, and some hybridization occurs (see comments under Jeffrey pine). Coulter pine extends southward into Baja California.

Thomas Coulter collected Coulter pine near Cone Peak in the Santa Lucia Mountains in 1831. Coulter's colleague and competitor, David Douglas, also collected this pine about the same time but did not publish it as a new species (Griffin 1964a).

**Pinus edulis** Engelm.
*pinyon* *Map 46*

This small, slow-growing pine ranges over much of Colorado, Utah, Arizona, and New Mexico (Critchfield and Little 1966, Fowells 1965). Over this distribution it is usually associated with one of several juniper species in an open "pinyon-juniper" woodland below the ponderosa pine forests.

The pinyon groves in California are the extreme western outposts of this interior species. These pinyon stands on the New York Mountains (Wolf 1938) are associated with singleaf pinyon. Munz (1959) lists an outlier of pinyon in the Little San Bernardino Mountains, but we have omitted this unconfirmed locality.

**Pinus flexilis** James
*limber pine* *Map 47*

*Pinus flexilis* ranges from southern Alberta east to South Dakota and south to New Mexico, where it intergrades with *Pinus strobiformis* (Critchfield and Little 1966). Limber pine's western distribution spreads over the desert mountain tops of southern and east-central California as far north as the Sweetwater Mountains. Several old maps incorrectly show limber pine much farther north in the Warner Mountains (Critchfield and Allenbaugh 1969).

This subalpine species is common on the east side of the Sierra Nevada crest in Inyo County—where we have no vegetation type data. A westside locality on the South Fork of the Kings River mentioned by Sudworth (1908) cannot be confirmed (Bacigalupi 1933).

The western limit of limber pine is in the Mount Pinos region of Kern and Ventura Counties. Ernest C. Twisselmann reports a limber pine on Brush Mountain northwest of Mount Pinos. Twisselmann (1967) mentioned limber pine on nearby Frazier Mountain in Ventura County, but neither Twisselmann nor we can confirm this now.

Other references: Clokey 1951, Howell 1946-49, Little 1966a, Lloyd and Mitchell 1966, Major and Bamberg 1963, Miller 1946, Peirson 1938, Roof 1969a.
Personal correspondence: Ronald J. Mastrogiuseppe, Feb. 17, 1969, Ernest C. Twisselmann, July 29, 1969, Feb. 2, 1970.

**Pinus jeffreyi** Grev. & Balf.
*Jeffrey pine* *Map 48*

Although basically a California species, Jeffrey pine extends 60 miles in the Klamath Mountains of Oregon to Myrtle Creek, almost entirely on serpentine soils. Throughout the Klamath Mountains and north Coast Ranges of California, Jeffrey pine predominates on serpentine soils. In this region Jeffrey pine grows on non-serpentine soils only on the higher ridges above 5,000 feet elevation, but on serpentine it extends as low as 200 feet.

North of the Pit River, in both the Cascades and Modoc Plateau, few Jeffrey pines grow. The eastern Siskiyou County stands shown in Critchfield and Little (1966) and Little (1971) seem to be in error. The main population in the Warner Mountains stops south of Cedar Pass. We have seen no native Jeffrey pines north of there, although John W. Duffield and Harry A. Fowells collected Jeffrey pine near the Buck Creek Ranger Station in the northern Warner Mountains. Jeffrey pine

has been extensively planted on the Modoc National Forest, and the Jeffrey pines at Sugar Hill and Hackamore are planted.

From Butte to El Dorado Counties, on a series of serpentine outcrops, Jeffrey pine is often found within the Mixed Conifer Forest at relatively low elevations. It occurs at 1,600 feet at Pulga. The normal pattern throughout the Sierra Nevada and in southern California is for ponderosa pine to occur in the Mixed Conifer Forest, with Jeffrey pine predominating at higher elevations in the Red Fir and Subalpine Forests. Where Jeffrey and ponderosa pines overlap, in the Sierra Nevada and elsewhere in the State, they often hybridize (Haller 1962). Chester B. Beaty found a few relict Jeffrey pines east of the Sierra Nevada in Jeffrey Mine Canyon in the White Mountains.

In the south Coast Ranges the only Jeffrey pine population is restricted to the highly serpentinized Clear Creek - New Idria region of San Benito County. This is the only place where the related Digger, Coulter, and Jeffrey pines grow together in mixed stands (Griffin 1965). Some hybridization between Coulter and Jeffrey pines occurs there. On Chews Ridge in Monterey County Jeffrey pine and hybrids between Coulter and Jeffrey pine grow within a Coulter pine forest (Zobel 1951). The Jeffrey pines on Chews Ridge, however, are thought to be planted (Zobel 1952). Periodically there are rumors of native Jeffrey pines in other parts of the Santa Lucia Mountains, but none of these reports has been confirmed.

In southern California Jeffrey pine increases in importance in the Mixed Conifer Forest and gradually replaces ponderosa pine, particularly in the interior areas (Haller 1962). Jeffrey pine occurs with Coulter pine in a number of places in southern California. Natural hybrids are present in the Laguna, San Bernardino, and San Jacinto Mountains (Zobel 1951). The Imperial - Riverside County locality shown in Little (1971) is in error—it coincides with the Salton Sea.

The southern limit of Jeffrey pine is in the Sierra San Pedro Martir, at least 150 miles south of the border in Baja California.

Other references: Grinnell and Storer 1924, Hemphill 1952, Howell 1940-42, 1946-49, Klyver 1931, Raven 1950-53, Twisselmann 1967.
Personal communication: Chester B. Beaty, Apr. 18, 1967.

**Pinus lambertiana** Dougl.
*sugar pine* *Map 49*

The northern limit of sugar pine is in Clackamas County, Oregon (Critchfield and Little 1966). In Oregon, sugar pine is common in the Mixed Conifer Forest of the Cascades and Siskiyou Mountains (Fowells 1965). In the Klamath Mountains and north Coast Ranges of California, sugar pines mix into several forest types as far south as the Mount St. Helena region. Several disjunct colonies of sugar pine grow in coastal Humboldt County in the Kings Range, and a large sugar pine population occurs at the inner edge of the Redwood Forest in the Gualala River region of Mendocino and Sonoma Counties.

In the Cascade - Sierra Nevada Range sugar pine is an important part of the Mixed Conifer Forest over a broad elevational range. Sugar pine is scattered in favorable habitats east of the Cascade crest as far as Island Butte, Lava Beds National Monument (Applegate 1938) and the Big Valley Mountains in Modoc County. Although conspicuous in the Mixed Conifer Forest above the 4,000- to 5,000-foot level, sugar pine does grow at an elevation of 2,000 feet west of Brownsville, Grass Valley, Applegate, and Garden Valley in the northern Sierra Nevada foothills. East of the Sierra Nevada, populations are scattered around the Lake Tahoe basin. A disjunct colony grows east of the main distribution on Owens Peak in Kern County (Twisselmann 1967).

Disjunct stands survive in Monterey County in the Cone Peak - Devils Canyon region and on Junipero Serra Peak. We have found no confirmation for Sudworth's (1908) report of sugar pine in the Santa Cruz Mountains.

Sugar pine is found at higher elevations across the San Gabriel, San Bernardino, and San Jacinto Mountains. Smaller populations occur on Hot Springs Mountain and the Cuyamaca Mountains in San Diego County. The southern limit is on Sierra San Pedro Martir in Baja California.

Other references: Klyver 1931, Powell 1968, Rockwell and Stocking 1969.

**Pinus monophylla** Torr. & Frem.
*singleleaf pinyon* *Map 50*

Singleleaf pinyon ranges from southern Idaho to Baja California, but is particularly abundant in Nevada (Critchfield and Little 1966). One outlier of the western Nevada population occurs southeast of Loyalton in Sierra County. Our limited data for the region suggests that from Alpine County southward, singleaf pinyon is common in the Pinyon-Juniper Woodland on arid ranges east of the Sierra Nevada. Singleleaf pinyon continues along the lower eastern slope of the Sierra Nevada into the Tehachapi Mountains, and forms an extensive woodland east of the South Fork of the Kern River. A few small stands of singleleaf pinyon occur west of the Sierra Nevada crest in the Tuolumne, San Joaquin, and Kings River drainages. Some of these westside stands, particularly the colony near Rancheria Creek above Hetch Hetchy, have been viewed as Indian introductions (Harwell 1937).

Singleleaf pinyon is common in northern Ventura County. In the upper Cuyama Valley the singleleaf pinyon woodland almost forms a "forest" (Twisselmann 1967). A few trees occur on top of the 8,000-foot Frazier Mountain. Eben McMillan found one tree on Caliente Mountain in San Luis Obispo County (Hoover 1970).

One singleleaf pinyon survives in a California juniper stand on the west side of the San Bernardino Mountains in the Santa Ana River Gorge (Axelrod 1967b, Sudworth 1908). In southern Riverside and San Diego Counties, Parry pinyon replaces singleleaf pinyon, with little overlap. A few singleleaf

pinyons appear in the Parry pinyon woodland near the California border. The southernmost singleleaf pinyon individuals are about 250 miles south of the California line in Baja California.

Other references: Clokey 1951, Cole 1963, Grinnell 1908, Grinnell and Storer 1924, Klyver 1931, Lewis and Gause 1966, Little 1956, Lloyd and Mitchell 1966, Miller 1946, Rockwell and Stocking 1969, Roof 1969a, St. Andre, Mooney, and Wright 1965, Weislander and Jensen 1945, Wells and Berger 1967.
Personal communication: Donald M. Black, July 7, 1970.

**Pinus monticola** Dougl.
*western white pine* *Map 51*

In the Rocky Mountains, western white pine ranges from southeastern British Columbia down into central Idaho (Critchfield and Little 1966). Throughout the Cascades this pine is a minor component in several higher-elevation forest types. In California it continues southward along the Sierra Nevada to the ridge between Big Meadow and Long Meadow in southern Tulare County. Western white pine is common in the Red Fir Forest. It is more common on the eastern slope of the southern Sierra Nevada than suggested by our incomplete data.

In the Klamath Mountains, western white pine is common as far south as the Trinity Alps region. Disjunct stands grow on Bully Choop and both North and South Yolla Bolly. In Del Norte County, western white pine is conspicuous on serpentine soils. On the Smith River near Panther Flat Campground it extends down to 500 feet elevation on serpentine.

Sudworth (1908) and other old references to western white pine in southern California all seem to be wrong.

Other references: Applegate 1938, Cooke 1940, Howell 1940-42, Klyver 1931, Little 1966a, Raven 1950-53.

**Pinus muricata** D. Don (including *P. remorata* Mason)
*bishop pine* *Map 52*

Thomas Coulter first collected bishop pine near San Luis Obispo in 1830. Since then the mainland distribution of this remarkably variable pine within the Closed-cone Pine Forest has become well known. One of the last populations to come to public attention was the northernmost stand on Luffenholz Creek near Trinidad Head, Humboldt County (Metcalf 1921). It is possible that the species did extend farther north, for Mason (1949) reported one tree in the coastal forest near Crescent City.

Critchfield and Little (1966) suggested that the range of bishop pine might almost overlap that of the more interior knobcone pine in southern Mendocino County. The SV survey map that this item was based on seems to be wrong—probably only bishop pine grows in the vicinity. Knobcone and bishop pines do approach within a few miles of each other near Lopez Canyon in San Luis Obispo County. We do not support Axelrod's (1967a) suggestion that knobcone pine recently grew within the bishop pine stands on the Purisima Hills of Santa Barbara County (see section on knobcone pine).

In Del Monte Forest on the Monterey Peninsula a bishop pine stand grows within the Monterey pine forest. The bishop pine associates with Gowen cypress on a sterile, partially podzolized soil. Wolf (1948) probably erred when he reported that bishop pine also grew at the Gibson Creek stand of Gowen cypress.

Linhart, Burr, and Conkle (1967) give a detailed account of bishop pine on Santa Cruz and Santa Rosa Islands. An island form of bishop pine with relatively symmetrical, smooth cones has been called *P. remorata.* This cone type also appears in the mainland populations in Santa Barbara County (Linhart, Burr, and Conkle 1967), and as far north as Marin County (Howell 1970). Axelrod (1967a) suggests that *P. remorata* grows on a different soil type than *P. muricata* on Burton Mesa in Santa Barbara County.

In Baja California there is a mainland occurrence of bishop pine near San Vicente. The southern limit of the species is on Cedros Island. The Cedros Island pine *(P. muricata* var. *cedroensis* Howell*)* differs from mainland bishop pine, and is difficult to distinguish from the Guadalupe Island form of Monterey pine *(P. radiata* var. *binata* Lemm.*).*

Other references: Critchfield 1967, Duffield 1951, Libby, Bannister, and Linhart 1968.

**Pinus ponderosa** Laws.
*ponderosa pine* *Map 53*

Ponderosa pine has an enormous distribution in western North America—almost as great as that of lodgepole pine (Critchfield and Little 1966). Ponderosa pine does not extend as far north into Canada as lodgepole pine, but various forms of ponderosa pine go farther south into Mexico.

Within California, ponderosa pine is one of the most widespread conifers in lower and middle elevation forests. It is important in all phases of the Mixed Conifer Forest. In the Klamath Mountains and north Coast Ranges ponderosa pine is also a minor component in open parts of the Mixed Evergreen and Douglas-fir Forests. In this region ponderosa pine is usually replaced on serpentine soils by Jeffrey pine. The north Coast Range distribution ends on the floor of the Napa Valley near St. Helena. In the south Coast Ranges ponderosa pine is scattered in the Mount Hamilton Range. In the Santa Cruz Mountains it is confined largely to special sandy habitats (Griffin 1964b). Ponderosa pine is common in the Santa Lucia Mountains. Occasional trees grow within a half mile of the coastline.

The Cascade-Sierra Nevada stands of ponderosa pine are virtually continuous southward into the Greenhorn Mountains of Kern County. South of the Kern River ponderosa pine grows on Breckenridge Mountain, but not on the Piute Mountains (Twisselmann 1967). In Shasta County individual pines are scattered along creek beds out into the Sacramento Valley at an elevation of 500 feet. In the Sierra Nevada

foothills scraps of ponderosa pine forest can be found below 2,000 feet in many areas, and individual trees follow stream courses to the 500-foot level in El Dorado County. East of the Sierra Nevada ponderosa pine is not common. In Nevada small stands occur as far east as the Virginia Range on special soils altered by hot spring activity. The VTM survey found a relict stand in the extremely arid region south of Pyramid Lake. In Mono and Inyo Counties most of the eastside ponderosa pines grow as riparian trees along creeks (Haller 1962). Several colonies of ponderosa pines survive in the White Mountains (Lloyd and Mitchell 1966).

In southern California there was some confusion between ponderosa and Jeffrey pines in the VTM mapping. When both species were clearly indicated in the vegetation type maps for a given locality we have followed the VTM identifications. This results in scattered ponderosa pine localities on the map in the Mount Pinos region where Vogl and Miller (1968) noticed only Jeffrey pines. The VTM maps also indicated ponderosa pines farther south in San Diego County than J. Robert Haller has found them. Haller is not sure that any ponderosa pines occur south of the Cuyamaca Peak region.

On the Modoc Plateau ponderosa pines are common in the open forest above the Northern Juniper Woodland. These "eastside" ponderosa pines are often morphologically and physiologically different from those of the main California distribution. They can be viewed as a more interior race (Haller 1962). At higher elevations in the Warner Mountains ponderosa pine tends to merge with Washoe pine (Haller 1961). A few ponderosa pines exist on sand dunes at the eastern end of the Madeline Plain, Lassen County in a very arid region (Griffin 1970). Critchfield and Allenbaugh (1969) described a grove of ponderosa pine in the extreme northwestern corner of Nevada and a tiny colony 20 miles farther east on Bald Mountain.

Other references: Clokey 1951, Duffield and Cumming 1949, Hemphill 1963, Jenkinson 1966, Klyver 1931, Lewis and Gause 1966.

Personal communication: Chester B. Beaty, Apr. 16, 1967.

**Pinus quadrifolia** Parl.
*Parry pinyon* *Map 54*

Parry pinyon is confined to a strip some 220 miles long (Critchfield and Little 1966). The bulk of this distribution is in Baja California. In California there are scattered trees in southeastern San Diego County. To the northwest, additional trees survive in fire-resistant spots between 4,000 and 6,000 feet on the steep eastern slope of the Laguna Mountains. A few singleleaf pinyons are also scattered in this region.

The main Parry pinyon population in California is in Riverside County. This population starts in the Santa Rosa Mountains and runs northwestward to Thomas Mountain and the head of Bautista Canyon. In general singleleaf pinyon lies on the eastern slopes in this area while Parry pinyon grows on western drainages. These Parry pinyons are not characteristically in open woodlands, but grow within dense chaparral communities. Parry pinyon does occur with Jeffrey pine in Garner Valley and Pine Meadows.

Personal correspondence: Eugene N. Anderson, Jr., Apr. 23, 1970.

**Pinus radiata** D. Don
*Monterey pine* *Map 55*

This pine has intrigued travelers to the Monterey Peninsula since Sebastian Vizcaino's visit in 1602. The scientific discovery came much later in 1830 when Thomas Coulter collected specimens at Monterey.

Monterey pine has a widespread fossil record in coastal California (Axelrod 1967a). But now Monterey pine survives naturally in only three mainland areas (Critchfield and Little 1966, Roy 1966b). The northernmost stand is in the Año Nuevo-Swanton vicinity. Over 30 miles to the south lie the more extensive Monterey-Carmel populations, and 65 miles farther south are the Pico Creek-Cambria groves. The southernmost stand on Guadalupe Island, 460 miles south of Cambria, differs in morphology from the mainland stands (see section on bishop pine).

The general boundaries of the three mainland localities have been well known for almost a hundred years. The precise natural limits, however, can no longer be determined. Natural seedlings from planted trees have obscured the edges of the pristine Monterey pine forests. We have no way of proving whether apparently non-planted trees in favorable habitats are relicts from native colonies. The three trees which Hoover (1970) describes near Avila illustrate this problem.

Another old boundary question concerns the Monterey stand. In 1784 John Sykes, the illustrator for the Vancouver Expedition, sketched near Toro Creek some trees that appear to be Monterey pines (Van Nostrand 1968). The locale is about 5 miles east of the traditional Monterey pine forest boundary. The pines in the illustration disappeared, and for perhaps a century pine trees were not known in that vicinity. Recently Monterey pines have been widely planted in the neighborhood.

At the Swanton locality Monterey pine meets the closely related knobcone pine, and some natural hybrids can be found. On the Monterey Peninsula a small bishop pine stand in Del Monte Forest is surrounded by Monterey pine forest. Here natural hybrids seem to be very limited if present at all (Forde 1964).

Despite the unimpressive "forestry" quality of the native California stands, Monterey pine has become one of the most widely planted and commercially valuable timber pines in the world. Hundreds of thousands of acres of Monterey pine have been planted in the Southern Hemisphere, particularly in Australia, New Zealand, and South Africa. When grown in a mild climate—free of its California pests and diseases—Monterey pine displays remarkably good growth.

Other references: Critchfield 1967, Libby, Bannister, and Linhart 1968.

**Pinus sabiniana** Dougl.
*Digger pine* *Map 56*

David Douglas collected this California endemic in 1831 while visiting Mission San Juan Bautista (Griffin 1964a). Digger pine is common throughout most of the Foothill Woodland at elevations of 1,000 to 3,000 feet from Shasta County to Los Angeles County (Griffin 1962). Low-elevation stands of Digger pine on the floor of the Sacramento Valley approach 100 feet elevation near Dunnigan, Natoma, and Oroville. Scattered groves occur in dry, rocky slopes within the Mixed Conifer Forest up to the 6,000-foot level. Such groves, particularly in the north, tend to be on sterile soils from serpentine rock (Griffin 1965). A few trees approach the 7,000-foot level near Sawtooth Peak in southwestern Inyo County.

Some distribution maps show Digger pine on the Sutter Buttes in the Sacramento Valley. Local rumors suggest that a few trees may have existed on the North Butte in the past, but no Digger pines seem to be there now. Jepson (1891) mentioned no pines in his early account of a trip to the Buttes, nor did the VTM survey record any there.

One strange feature of Digger pine's distribution is a 55-mile-wide gap in the southern Sierra Nevada foothills. This gap is difficult to explain, for the topography, soils and general vegetation are rather constant across this area. But for some reason Digger pine is missing from the Foothill Woodland between the Kings River and the South Fork of the Tule River. Josiah D. Whitney commented on this gap as early as 1865.

Several old reports place Digger pine in San Bernardino and San Diego Counties, but these rumors seem to be based on Coulter pine. The extreme southern limit is on Piru Creek in Ventura County (Axelrod 1967b).

Since the 1830's, when David Douglas mixed up some of his Oregon and California field observations, there have been many rumors of Digger pine growing in Oregon. All of these reports are questionable. Oliver V. Matthews did, however, find a Digger pine growing near the Rogue River west of Gold Hill, Oregon, in 1945. There is no evidence that this tree was a relict of a natural population. Yet several California species do occur naturally in this region. If Digger pine did grow in Oregon, the Medford-Grants Pass portion of the Rogue River Valley would certainly be an appropriate habitat. Jepson's (1910) report of the northern limit on the South Fork of the Salmon River in Siskiyou County seems to stand. The extreme northwestern outlier was probably on Redwood Creek, where C. Hart Merriam reported a few trees at the "Bair Ranch" in 1907. We have been unable to confirm this report.

One interesting population of Digger pines is on the fringe of the Northern Juniper Woodland in the central Pit River drainage (Griffin 1966). The pines there, ranging up to 5,000 feet on the Hat Creek Rim, are completely isolated from the main Foothill Woodland populations. These Modoc Plateau groves are in dramatic contrast to the southern Monterey County habitats, where Digger pine populations come almost down to the surf. The single tree that Coleman (1905) reported on the Monterey Peninsula was probably planted there.

Other references: Knight 1969, Sudworth (n/d).

**Pinus torreyana** Parry
*Torrey pine* *Map 57*

One of the truly rare conifers, Torrey pine is now restricted to two places in southern California. The mainland population is sprinkled along the low coastal bluffs on both sides of the Soledad Valley north of San Diego. Parry collected specimens from this stand in 1850. Jepson (1910) estimated that the pine covered a strip 8 miles long. Our map, based on 1931 VTM survey data, shows less than a 5-mile range. Recent estimates place the total number of trees in the mainland population at around 6,000. Most of the remaining pines south of Soledad Valley are in the Torrey Pines State Reserve. Recently 170 acres of the northern grove, with some 1,500 trees, were added to the reserve.

The Santa Rosa Island population is some 175 miles to the northwest. Haller (1967) estimated the stand as one-half mile long and one-quarter mile wide, ranging in elevation from 200 to 500 feet.

**Pinus washoensis** Mason & Stockwell
*Washoe pine* *Map 58*

This high-elevation relative of ponderosa pine is scattered in widely separated spots along the western edge of the Great Basin. It first came to botanical attention through the VTM survey. The field crew mapping on the east slope of Mount Rose, Nevada, noticed that it differed from the local Jeffrey and ponderosa pines, and in 1945 Washoe pine was formally described as a new species.

On Mount Rose, Washoe pine occupies hundreds of acres near the head of Galena Creek at an elevation of 7,000 to 8,000 feet. It is surrounded by Jeffrey pine. Typical ponderosa pine occurs at a lower elevation less than 2 miles away. In 1961, Haller reported on a more extensive stand of Washoe pine in the southern Warner Mountains of Modoc County. Critchfield and Allenbaugh (1965) found several hundred Washoe pines on the Bald Mountain Range 20 miles northwest of Mount Rose. According to Haller (1961), Washoe pines may also be occasional in a variable population of ponderosa and Jeffrey pines between Hobart Mills and Boca. Haller has found individual Washoe pines on Last Chance Creek in Plumas County, and John Thomas Howell discovered several trees near Butte Lake in Lassen Volcanic National Park.

On Mount Rose and the Bald Mountain Range, Washoe pines are isolated from and morphologically distinct from

ponderosa pine. In the Warner Mountains Washoe pines are recognizable at higher elevations (around 8,000 feet) and typical ponderosa pines at lower elevations, but there is a broad zone of intermediates. Haller (1965) reports that farther north in Oregon Washoe pine and the interior form of ponderosa pine are even less distinct.

Other references: Mason and Stockwell 1945, Smith 1971.
Personal correspondence: J. Robert Haller, Oct. 14, 1969.

## *Platanus* sycamores

(Plantanaceae Sycamore Family)

The sycamore family has only one genus with about 10 species, all in the Northern Hemisphere. Seven species of sycamores grow in North America, three in the United States. The Arizona sycamore, *P. wrightii* S. Wats., is closely related to the California sycamore, *P. racemosa,* and has been considered a variety of *racemosa* by Benson (1943). We could find no support for the suggestion (Benson and Darrow 1945, Little 1950) that *P. wrightii* grows locally in "southeastern" California.

**Platanus racemosa** Nutt.
*California sycamore* *Map 59*

California sycamores never grow on dry, upland slopes. Instead they congregate along live streams, around springs, or in gullies with underground water. Yet the over-all distribution of this species resembles that of no other riparian tree in California.

In the Central Valley, sycamore grows at low elevations along streams from Shasta County (Jepson 1908, 1910) to Kern County (Twisselmann 1967). It was conspicuous in the pristine riparian forests in the Sacramento Valley (Thompson 1961). Although sycamore is locally abundant in parts of the Central Valley, its distribution is spotty. Our data are incomplete for the central portion of the valley. Even so, sycamores are missing from many streams where we would have expected them. Jepson (1910) remarked on the absence of sycamores in the north Coast Ranges and the west side of the Sacramento Valley. We have found no sycamore records for that region either.

In the south Coast Ranges and in southern California sycamore trees are sprinkled abundantly through a wide elevational range. Every likely canyon and creek bottom has sycamores. As Jepson (1910) observed, sycamore is one of the most widely distributed arboreous species there. Sycamore is not known to extend eastward into the Mojave region. The sycamores on Santa Catalina Island appear to be planted (Thorne 1967). California sycamores do continue southward into Baja California.

Other references: Howell 1970, Klyver 1931, Raven and Thompson 1966, Thomas 1961.

## *Populus* poplars, cottonwoods

(Salicaceae Willow Family)

*Populus* is a large, widespread genus in the North Temperate Zone, with some 30 to 35 species. About 15 poplar species are native to North America, four extending into California.

**Populus angustifolia** James
*narrowleaf cottonwood* *Map 60*

This interior cottonwood ranges from southern Alberta, Canada, south into Chihuahua, Mexico. It is the common cottonwood in much of the Rocky Mountain region. California is on the western edge of this distribution. Munz (1959) listed collections from Lone Pine Creek and Division Creek on the east side of the Sierra Nevada. Lloyd and Mitchell (1966) reported narrowleaf cottonwood on Wyman Creek in the White Mountains. The *Populus acuminata* Rydb. reported by DeDecker from Lone Pine Creek (Munz 1968) may be a hybrid derivative of some combination of *P. angustifolia, P. trichocarpa*, and *P. fremontii,* all of which grow there.

Other references: Clokey 1951, Little and Archer 1965.

**Populus fremontii** S. Wats. (including in part var. *arizonica* [Sarg.] Jeps., *pubescens* Sarg., and *macdougalii* [Rose] Jeps.)
*Fremont cottonwood* *Map 61*

This variable cottonwood species stretches across the Southwest in wet places from California to Utah, Texas, and Mexico (Little 1971). A number of specific and varietal names have been proposed within the *P. fremontii* complex.

Our distribution map for this riparian species is not entirely satisfactory. The species is so spotty that it was seldom typed on vegetation maps. Even if we had data on every spring, seep, creek, and irrigation ditch, we could not adequately plot all the localities. Fremont cottonwood has also been so widely planted and naturalized that its truly "native" range is now obscure. It is a pioneer species on dredger tailings east of Sacramento and elsewhere in the Central Valley.

Within California, Fremont cottonwood is uncommon in the Klamath Mountains and north Coast Ranges. Some stands do occur on the upper Trinity and Eel drainages. Jepson (1910) erred in listing the northern limit as near Redding. Some Fremont cottonwood grows in the Sacramento River Canyon north of Redding, and a disjunct stand grows along Moffett Creek, near Fort Jones in Siskiyou County. Fremont cottonwood was prominent in the pristine riparian forest of the Sacramento Valley (Thompson 1961), and it is still abundant in wet spots throughout much of the Central Valley. Disjunct colonies grow on Santa Cruz, Santa Catalina (Thorne 1967), and San Nicolas Islands (Foreman 1967). We probably have shown only a small part of the isolated colonies in the Mojave Desert. Fremont cottonwood is abundant along the Colorado River (Grinnell 1914).

In California, Fremont cottonwood seems to prefer relatively low-elevation habitats, but near the coast it is usually replaced by black cottonwood. At higher elevations in the Coast Ranges and Sierra Nevada, Fremont cottonwood is sometimes replaced by black cottonwood, but more commonly there is an elevational discontinuity between the two cottonwoods. In western Nevada, Fremont cottonwood again becomes locally common.

Other references: Buttery and Green 1958, Coville 1893, Howell 1970, Klyver 1931, Lloyd and Mitchell 1966, Parish 1930, Powell 1968, Thomas 1961, Twisselmann 1967, Vogl and McHargue 1966, Wetzel 1971.
Personal communication: Peter G. Sanchez, Aug. 4, 1970.

**Populus tremuloides** Michx.
*quaking aspen, aspen* *Map 62*

In North America no other tree species is as wide-ranging as quaking aspen (Fowells 1965). A major portion of this range is in Alaska, Canada, and the northeastern United States. Aspen also extends south well into Mexico.

The southern limit in California is an exceedingly isolated colony near the 7,500-foot level on Fish Creek in the San Bernardino Mountains (Grinnell 1908). The Sierra Nevada distribution starts about 150 miles to the north at Horse Meadow in southern Tulare County. In the Sierra Nevada, quaking aspen is locally abundant in moist, high-elevation habitats–often around the edges of meadows. Disjunct colonies grow east of the Sierra Nevada in the White Mountains (Lloyd and Mitchell 1966).

Our data on distribution in the Cascades and Modoc Plateau are incomplete. Quaking aspen is more scattered there, however, and often grows at lower elevations. Besides bordering creeks and meadows, it is also sprinkled over steep, barren lava talus slopes in this region. At McArthur-Burney Falls State Park aspen grows as low as 3,000 feet. Jepson (1923) doubted that aspen grew on Mount Shasta, but Cooke (1940) found it on Shastina and Pilgrim Creek. Extensive shrubby thickets of aspen appear on the upper slopes of the Warner Mountains.

Aspen is not common in the Klamath Ranges. Little (1971) shows only one locality west of the Sacramento River drainage; and Jepson (1923) knew of only one locality, Canyon Creek in Trinity County. Actually, aspen is scattered in a number of remote places in this region including the Trinity Alps, Russian Peak, and the Marble Mountains. The southern extreme in the Klamath Ranges seems to be in Cedar Basin, just south of North Yolla Bolly Mountain.

Other references: Gillett, Howell, and Leschke 1961, Grinnell and Storer 1924, Howell 1940-42, 1946-49, Lewis 1966, Little 1966a, Little and Archer 1965, Maciolek and Tunzi 1968, Raven 1950-53, Rockwell and Stocking 1969, Roof 1969a.

**Populus trichocarpa** Torr. & Gray
*black cottonwood* *Map 63*

Black cottonwood ranges from southern Alaska east to North Dakota and south into Baja California (Fowells 1965). Brayshaw (1965) considered black cottonwood to be a western subspecies of the balsam poplar, *Populus balsamifera* L.

In Washington and Oregon black cottonwood forms extensive bottomland forests along the streams and sometimes on the adjacent uplands, but in California it stays close to water courses. Black cottonwood is locally common on coastal streams, and is particularly conspicuous in the lower Eel River drainage. It may associate with red alder near tide level. In the warmer, more interior valleys and foothills black cottonwood is replaced by Fremont cottonwood. Although it is abundant on streams around Monterey Bay, black cottonwood is absent from Marin County (Howell 1970) and much of the San Francisco Bay region. Jepson (1910) reported black cottonwood in Mitchell Canyon, Mount Diablo, but Bowerman (1944) listed only Fremont cottonwood from the same area. Disjunct colonies grow on Santa Catalina (Munz 1935), Santa Cruz, and Santa Rosa Islands.

At higher elevations in the mountains throughout California black cottonwood sporadically reappears near streams, springs, and lakes–sometimes overlapping the range of quaking aspen. In the southern Sierra Nevada black cottonwood may be found up to 10,000 feet elevation.

Other references: Grinnell 1908, Hall 1902, Hall and Hall 1912, Howell 1940-42, Lloyd and Mitchell 1966, Meyer 1931, Powell 1968, Raven 1950-53, Raven and Thompson 1966, Roof 1969a, Sharsmith 1945, Smith 1952, Stebbins 1968, Thomas 1961, Twisselmann 1967, Wetzel 1971.
Personal communication: Reid Moran, Oct. 12, 1970.

## *Prunus* cherries, plums

**(Rosaceae Rose Family)**

This large, variable genus of shrubs and trees includes some 150 to 175 species. About 25 species are native to the United States. Eight species grow in California, and one of these is endemic to the California islands.

Many of the shrubby California plums and cherries reach tree size in favorable spots–*Prunus emarginata* (Dougl.) Walp., *P. virginiana* var. *demissa* (Nutt.) Sarg., *P. subcordata* Benth. Individuals of *Prunus ilicifolia* (Nutt.) Walp., are sometimes very large; Twisselmann (1956) describes one at Cherry Spring in the Temblor Range as 24 feet tall with a trunk 11.5 feet in circumference. James R. Griffin measured one *P. ilicifolia* in the Carmel Valley in 1971 that was 47 feet tall. However, none of these species is consistently tree-like, and they are not mapped.

**Prunus lyonii** (Eastw.) Sarg. (*P. ilicifolia* ssp. *lyonii* [Eastw.] Raven)
*Catalina cherry* *Map 64*

Catalina cherry is closely related to *Prunus ilicifolia,* and some botanists consider it an insular form of the mainland species. Catalina cherry is more consistently of tree form and size than *P. ilicifolia.*

Catalina cherry is mainly confined to Santa Catalina, Santa Cruz, Santa Rosa, San Clemente, and Anacapa Islands. Alice Eastwood reported typical *P. ilicifolia* on Santa Catalina Island, but Thorne (1967) could find only *P. lyonii* there. Reports of *P. lyonii* on the mainland in Baja California may be based on *P. ilicifolia.*

Other references: Raven 1963.

## *Pseudotsuga* Douglas-firs

**(Pinaceae Pine Family)**

This genus includes about six species, all in the Northern Hemisphere. Two species grow in North America. Both of these Douglas-firs are found in California, and one is endemic to the State. A host of specific names have been proposed within the American Douglas-fir species, particularly by the French taxonomist F. Flous. But these species have never gained wide acceptance in California.

**Pseudotsuga macrocarpa** (Vasey) Mayr
*bigcone Douglas-fir (bigcone-spruce)* *Map 65*

This southern California species is probably restricted to the State. Gause (1966) lists all the old references which suggest that bigcone Douglas-fir grows in Baja California. The bases for these reports are vague, and Ira Wiggins doubts them (Bolton and Vogl 1969). Bolton and Vogl (1969) report the southern limit to be near Banner and San Felipe[2] Canyons in San Diego County, but the VTM survey found scattered trees in Chariot Canyon south of Banner.

The bulk of the bigcone Douglas-fir range was covered by the VTM survey, and our map for this species is relatively complete. Some details of the distribution have probably been altered by fire in the 30 years since completion of the VTM field work. In elevation, this species ranges from a low of 900 feet in the chaparral up to 8,000 feet in the Mixed Conifer Forest (Gause 1966).

The northernmost stands of bigcone Douglas-fir are in the Mount Pinos region of Kern County (Twisselmann 1967). The VTM survey mapped two trees as far north as Eagle Rest Peak in Kern County and slightly farther north in the Sierra Madre of Santa Barbara County at the head of Labrea Creek. The western limit is on Zaca Peak. This *P. macrocarpa* locality is about 21 miles from the closest outpost of *P. menziesii* (Griffin 1964c).

**Pseudotsuga menziesii** (Mirb.) Franco
*Douglas-fir* *Map 66*

Douglas-fir grows extensively through western North America (Fowells 1965). The interior variety extends from central British Columbia southward to central Mexico. The coastal form dominates vast portions of western Oregon and Washington between the coastal spruce zone and the fir forest of the higher Cascades.

In California extensive stands of Douglas-fir continue southward through the Klamath and Coast Ranges as far as the Santa Cruz Mountains. Douglas-fir mixes into the eastern portion of the Redwood Forest and dominates the Douglas-fir and much of the Mixed Evergreen Forests. In the Santa Lucia Mountains Douglas-fir stands are well developed only on the Little Sur River. Scattered groves appear in the Limekiln Creek, Willow Creek, and Salmon Creek drainages. Clare B. Hardham sent us a Douglas-fir specimen from San Carpoforo Creek just south of the Monterey County line. The VTM survey found one old, apparently non-planted Douglas-fir tree within the Monterey pine forest, east of Monterey. Douglas-fir has recently been planted in this same vicinity.

The southern limit for Douglas-fir in the Coast Range is an extremely isolated colony in the Purisima Hills (Griffin 1964c). This grove is within a bishop pine forest on diatomaceous earth. These *P. menziesii* trees are only 21 miles away from the closest stand of *P. macrocarpa* on Zaca Peak.

In the Sierra Nevada-Cascade Range, Douglas-fir is a common part of the Mixed Conifer Forest as far south as the Yosemite region. Douglas-fir skips most of Madera County, and the southern outpost in the Sierra Nevada is near Big Creek in Fresno County.

In California, Douglas-fir is largely restricted to forests west of the Cascade - Sierra Nevada crest. Billings (1954) mentioned a Douglas-fir collection from Glenbrook on the east shore of Lake Tahoe, but the VTM survey did not find any Douglas-fir in this area. In Lassen County a few Douglas-fir groves occur on the eastern flank of the Sierra Nevada between Honey Lake and Susanville.

Other references: Howitt and Howell 1964, McKeever 1961. Personal correspondence: Clare B. Hardham, Dec. 28, 1968, Gordon R. Foster, May 7, 1971.

## *Quercus* oaks

**(Fagaceae Beech Family)**

*Quercus* is a huge Northern Hemisphere genus with some 300 tree and shrub species. Countless hybrids and questionable species have been described in the genus. About 68 oak species grow in the United States. Fifteen different oaks are present in California. *Quercus gambelii* Nutt. comes close to California in

[2]See Geographic Location of Place Names, footnote 3, for comment on this place name.

southern Nevada (Little 1971). Nine California species are predominantly of tree size and form and are mapped. Two of these species, blue oak and valley oak, are endemic to the State. Many of the others have the bulk of their distributions in California.

**Quercus agrifolia** Née (including the shrubby var. *frutescens* Engelm.)
*coast live oak, California live oak* *Map 67*

The early Spanish and Mexican settlers in California were well acquainted with this live oak, which they called "encina." In 1602 Sebastian Vizcaino, the first European to land at Monterey, held a religious ceremony under a coast live oak on the shore of Monterey Bay. Fray Junipero Serra supposedly said mass under the same live oak in 1770. The scientific collection of this species came in 1791 when the Malaspina Expedition visited Monterey. As Jepson (1910) noted, the range of coast live oak corresponds well with the Mexican sphere of influence in California during the Mission period.

Typical *Q. agrifolia* is common in northern Sonoma County. It extends farther north into Mendocino County along the Russian River to Hopland and northwest to Anderson Valley. In Mendocino County *Q. agrifolia* seems to hybridize readily with *Q. wislizenii,* and it is difficult to tell where the coast live oak distribution ends.

Coast live oak crosses the Coast Ranges in Napa County, reaching the edge of the Sacramento Valley along several creeks in Yolo County. Some *Q. agrifolia* trees are scattered up the Sacramento River in the Delta region as far as Courtland. Coast live oak populations also extend over the Coast Ranges at Pacheco Pass. The VTM survey mapped a few trees in southwestern Fresno County. Twisselmann (1967) listed western Kern County colonies at Bill Little Spring and Drake Ridge in the Temblor Range.

Coast live oak is most abundant in the valleys and lower slopes as part of the Foothill Woodland and the southern California phase of the Mixed Evergreen Forest. In the north it seldom exceeds the 3,000-foot level, but in the south it may approach 5,000 feet. Within the range of coast live oak, *Q. wislizenii* tends to grow in a shrubby form in chaparral above the *Q. agrifolia* woodlands. The more interior *Q. agrifolia* stands in southern California have been called var. *oxydenia* (Torr.) J. T. Howell. Hoover (1970) applied this name to pubescent forms as far north as San Luis Obispo County. Coast live oak extends southward into Baja California.

Other references: Cooper 1926, Howell 1970, Thomas 1961, 1970, Twisselmann 1956.

**Quercus ×alvordiana** Eastw. *Map 68*

In 1894, Alice Eastwood collected some scrubby oaks in San Emigdio Canyon, Kern County, which she later described as *Q. alvordiana.* The variable group of semi-deciduous oaks associated with this name is not a satisfactory taxonomic unit (Tucker 1952a). In form they are not always satisfactory trees either. These problem oaks, however, should be considered if the southern distribution of *Q. douglasii* is to be fully understood.

Tucker (1952a,b) has shown that the name *Q. alvordiana* applies to small trees which are morphologically intermediate between deciduous *Q. douglasii* trees and evergreen *Q. turbinella* Greene shrubs. The origin of the "alvordiana" problem must have involved past hybridization between these two species. The problem is complicated by the merging of the interior *Q. turbinella* shrubs with the coastal *Q. dumosa* Nutt. shrubs.

The "alvordiana" hybrids are not just local novelties sprinkled around where the two parental species overlap. They are a conspicuous part of the inner Coast Range vegetation from the upper Carmel Valley in Monterey County southward into the Tehachapi Mountains. In places the dominant oak of the Foothill Woodland is not typical *Q. douglasii* but rather *Q. ×alvordiana.* Since these hybrids are such a vague entity, we have mapped only the generalized region where they appear. The map is largely based on what the VTM survey called the "tree" form of *Q. dumosa.*

Other references: Benson et al. 1967, Hoover 1970, Twisselmann 1967.

**Quercus chrysolepis** Liebm. (including the shrubby var. *nana* Jepson).
*canyon live oak* *Map 69*

Canyon live oak's distribution starts in southwestern Oregon and runs southward into Baja California and eastward to central Arizona (Tucker and Haskill 1960). Most of the literature states that *Q. chrysolepis* ranges eastward to New Mexico. All New Mexico and some Arizona reports of *Q. chrysolepis* are probably based on the closely related *Q. dunnii* Kell. or the unrelated *Q. turbinella.*

Within California, canyon live oak is the most widely distributed oak. In various tree and shrub forms it covers a vast array of forest, woodland, and chaparral habitats. As the common name implies, it is conspicuous on steep, rocky canyon slopes. At higher elevations in the Sierra Nevada and Klamath Mountains *Q. chrysolepis* is replaced by the related shrubby species, *Q. vaccinifolia* Kell. Canyon live oak is scattered on the east slope of the southern and central Sierra Nevada. It does not cross the Cascades, nor does it extend into Lassen National Park (Gillett, Howell, and Leschke 1961). It is rare on the north side of Mount Shasta (Cooke 1941).

Disjunct stands occur on the Providence and New York Mountains (Tucker and Haskill 1960). A few canyon live oaks appear on the southern California islands where they hybridize with the closely related *Q. tomentella* (Muller 1967).

Other references: Howell 1940-42, 1970, Howell, Raven, and Rubtzoff 1958, McClintock and Knight 1968, McMinn 1951, Oberlander 1953, Thomas 1961.

Personal correspondence: Enid A. Larson, Feb. 7, 1971, John M. Tucker, Nov. 16, 1970.

**Quercus douglasii** Hook. & Arn.
*blue oak* *Map 70*

Blue oak is the conspicuous deciduous oak in the Foothill Woodland surrounding the Central Valley. The main distribution reaches northward to Montgomery Creek in Shasta County. Scattered blue oak trees occur above the McCloud River arm of Shasta Lake. An isolated population grows east of the Cascades near Pit River Powerhouse No. 1 (Griffin 1966). To the west, in Trinity County, another isolated population grows in the Browns Creek-Reading Creek area.

Sierra Nevada foothill stands extend onto the floor of the Sacramento Valley in many areas. Blue oaks are common on the Sutter Buttes in the valley. A large extension of the Coast Range population into the Sacramento Valley occurs in the Dunnigan-Arbuckle area (Griffin 1962).

In the south the main distribution stops in the Liebre Mountains of Los Angeles County and the Santa Ynez Valley of Santa Barbara County. A few trees above Mission Santa Barbara are less than 3 miles from the coast. Small groves of blue oak occur on Santa Cruz and Santa Catalina Islands (Muller 1967).

In various parts of its distribution *Q. douglasii* grows with many other species of the "white oak group." Blue oak appears to hybridize with at least *Q. dumosa, Q. garryana, Q. lobata,* and *Q. turbinella.* Hybridization with *Q. turbinella* is the most significant (see section on *Q.* ×*alvordiana*).

Other references: Howell 1970, Lewis and Gause 1966.

**Quercus engelmannii** Greene
*Engelmann oak (mesa oak)* *Map 71*

Engelmann oak has a limited distribution in southern California and adjacent Baja California. Southward from Los Angeles County *Q. douglasii* in the Foothill Woodland is replaced by Engelmann oak in the Southern Oak Woodland. Engelmann oak is scattered along the base of the San Gabriel Mountains between Pasadena and San Dimas. The VTM survey also mapped a few isolated *Q. engelmannii* trees in Riverside County near Hemet. An 1878 specimen by John G. Lemmon in the University of California Herbarium was labeled San Bernardino County, but gave no definite locality. The main distribution lies in western San Diego County, usually below 4,000 feet in elevation. One specimen was collected on Santa Catalina Island (Thorne 1967).

Engelmann oak appears to hybridize locally with *Q. lobata* and *Q. dumosa.* Jepson's (1910) suggestion that Engelmann oak occurred in the San Carlos and Mount Hamilton Ranges has no modern confirmation, and may have been based on hybrid forms of *Q. douglasii.*

Other references: Boughey 1968, Munz 1959.

**Quercus garryana** Dougl. (including varieties *brewerii* [Engelm.] Jeps. and *semota* Jeps.)
*Oregon white oak, Garry oak* *Map 72*

This is the only oak species in California that extends far beyond the State's boundaries. Oregon white oak is scattered northward into southwestern British Columbia (Fowells 1965). In Oregon it is abundant in the Willamette Valley, and it spreads across the Klamath Mountains in dry, warm portions of the Douglas-fir and Mixed Evergreen Forests. In California it continues to be common in the Klamath Mountains and north Coast Ranges—as a dominant in the Northern Oak Woodland, as a minor part of several forest types, and as a brushfield shrub on sterile soils.

South of Marin County, Oregon white oak is rare. Thomas (1961) mentioned only two localities in the Santa Cruz Mountains. Tucker (1953) found a single tree northeast of Gilroy. Hoover (1970) reported *Q. garryana* in San Luis Obispo County, but we have identified his collections as *Q. lobata.*

Oregon white oak crosses the Cascades and reaches up the Pit River drainage to the Big Valley Mountains in Lassen County. This oak continues southward in an interrupted belt all the way to the Tehachapis (Twisselmann 1967). Tucker (1950) found one isolated tree in Bouquet Canyon in Los Angeles County.

Jepson's (1910, 1923) comments on the shrubby forms of *Q. garryana* are not too helpful. He suggests that var. *brewerii* is a high-elevation shrub in the Klamath Mountains and that var. *semota* is a shrub isolated in the southern Sierra Nevada. Actually, the shrubby *Q. garryana* in northwestern California occupies a wide range of elevations. Its isolation from the Sierra Nevada shrubs is not great, either geographically or morphologically (McMinn 1951). Large brushfields of *Q. garryana* were mapped by the SV survey in the Cascade foothills from Shasta County south into Butte County. More widely scattered foothill stands connect with the *semota* populations of the south. Twisselmann (1967) called the extensive *Q. garryana* brushfields in Kern and Los Angeles Counties the "Shin oak brush" association.

Other references: Bowerman 1944, Howell 1970.

**Quercus kelloggii** Newb.(including the shrubby form *cibata* Jeps.)
*California black oak* *Map 73*

This oak has a broad distribution in California—almost as great as that of canyon live oak. California black oak ranges northward to the vicinity of Eugene, Oregon. According to Ira L. Wiggins its southern limit is in the Laguna Mountains of San Diego County. It does not cross into Baja California (McDonald 1969).

California black oak is abundant in the lower portions of the Mixed Conifer Forest, and it is also common in parts of the Mixed Evergreen Forest. This species ranges farther east of the Cascades than the other California oaks. California black

oak is the only oak with significant populations in Modoc County, as far east as Adin Pass. In Lassen County *Q. kelloggii* is scattered along the eastern base of the Sierra Nevada. Stands on the east side of the Sierra Nevada in Inyo County were mentioned by Jepson (1910). As McDonald (1969) suggests, ponderosa pine is probably the most common associate of California black oak, but their ranges do not coincide in many regions.

*Quercus kelloggii* occasionally hybridizes with *Q. wislizenii* in areas where their ranges overlap. In 1863 Albert Kellogg described these semi-deciduous intermediates as *Q. morehus,* and controversy about their origin lasted for decades (Jepson 1923). At times hybrid-like individuals appear in localities now far removed from one of the parental species. For example, "morehus" hybrids may occur on Santa Cruz Island, but no *Q. kelloggii* grows there now (see interior live oak for additional comments on this hybrid). In the south Coast Ranges *Q. kelloggii* also hybridizes with *Q. agrifolia.* These hybrids were first described as *Q.* ×*ganderi* C. B. Wolf.

Other references: Bowerman 1944, Grinnell 1908, Hoover 1970, Howell 1970, McClintock and Knight 1968, McMinn 1951, Raven 1950-53.
Personal correspondence: George Dobbins, Aug. 29, 1970, Enid A. Larson, Feb. 7, 1971.

**Quercus lobata** Née
*valley oak, California white oak* *Map 74*

Valley oak, called "roble" by the Spanish, was first collected by the Malaspina Expedition near Monterey in 1792. Huge valley oaks, which dotted the fertile lowlands, impressed the early settlers. As Jepson (1923) noted, valley oaks were often "the sign of the richest soil."

The northern limit of this endemic species seems to be near Lakehead above the Sacramento River arm of Shasta Lake. Valley oak stands were mapped along the lower Pit and McCloud Rivers by the VTM survey before the flooding of Shasta Lake. We could find no confirmation of Jepson's (1910) report of valley oak on the Trinity River. According to Joseph P. Tracy the northwestern limit is in Ten Mile Valley, northwest of Laytonville in Mendocino County.

Valley oak was a conspicuous part of the riparian forests in the Sacramento Valley (Thompson 1961). It also grows along part of the lower San Joaquin River. Valley oaks were common over the alluvial fans of the larger rivers coming down from the Sierra Nevada. The valley oak woodland on the Kaweah River plains around Visalia may have been the most extensive in the San Joaquin Valley. It should be emphasized that valley oaks were not generally distributed in the Central Valley. Large portions of the valley were devoid of any trees.

Valley oaks are by no means restricted to alluvial soils in the Central Valley or within the Foothill Woodland region around the valley. In the south Coast Ranges they are a minor component of several mixed-species upland communities. They often become conspicuous on the open savannas of the broader ridge tops. On Chews Ridge in Monterey County valley oaks grow at 5,000 feet. In the Tehachapi Mountains valley oaks reach the 5,600-foot level in association with Jeffrey pine (Twisselmann 1967). In southern Monterey County a few valley oaks grow within a mile or so of the coastline.

The main distribution stops near the San Fernando Valley in Los Angeles County. Abrams (1910) collected one specimen near Santa Monica. Typical valley oak occurs on Santa Cruz and Santa Catalina Islands (Muller 1967). Hybrids between *Q. lobata* and *Q. dumosa,* sometimes called *Q. macdonaldii* Greene, are present on these islands and also on Santa Rosa Island. Similar hybrids appear on the mainland as far south as Orange County (Boughey 1968). Tucker (1968) described a hybrid between *Q. turbinella* and *Q. lobata* on the Joshua Tree National Monument.

Other references: Cooper 1926, Klyver 1931, Howell 1970, Thorne 1967, Tracy (n/d), Twisselmann 1956.

**Quercus tomentella** Engelm.
*island live oak* *Map 75*

This insular oak is the rarest of the California oaks. Although fossils have been found on the mainland, *Q. tomentella* is restricted to the islands (Muller 1967). Edward Palmer discovered it on Guadalupe Island off the Baja California coast in 1875. Island oak is now known from five of the California islands: Anacapa, San Clemente, Santa Catalina, Santa Cruz, and Santa Rosa. *Quercus tomentella* is closely related to *Q. chrysolepis.* A few typical canyon live oaks occur on the islands, but most of the canyon live oak there seem to be influenced by hybridization with island oak.

**Quercus wislizenii** A. DC. (including the shrubby var. *frutescens* Engelm.)
*interior live oak* *Map 76*

Interior live oak is largely a California species, but it does range south into Baja California. As the name implies, interior live oak ranges farther inland than coast live oak. Along the lower slopes of the Sierra Nevada and Cascades it is part of the Foothill Woodland. In some places it forms dense, shrubby thickets just below the Mixed Conifer Forest.

The northern limit is in southern Siskiyou County, but hybrids between interior live oak and California black oak have been found in southern Oregon (Anonymous 1948, Matthews 1948). Such *Q.* ×*morehus* hybrids also occur on Hat Creek Rim east of the Cascades (Griffin 1966) (see section on California black oak for additional comments on this hybrid).

In the north Coast Ranges, interior live oak occupies a variety of forest, woodland, and chaparral habitats. In much of the south Coast Ranges and southern California distribution it is shrubby and grows at higher elevations than coast live oak. In the Santa Cruz and Santa Lucia Mountains, however, interior live oak trees provide much of the hardwood understory in the Redwood Forest.

One locality of interior live oak lies on the east side of the Sierra Nevada, on Oak Creek in Inyo County (Haller 1962).

Other references: Buttery and Green 1958, Havlik 1970, Howell 1970, Klyver 1931, Muller 1967, Raven and Thompson 1966, Thomas 1961, Twisselmann 1967.
Personal correspondence: Enid A. Larson, Feb. 7, 1971.

## *Sequoia* redwood

**(Taxodiaceae Taxodium Family)**

Fossil records show that *Sequoia* was once widespread in the Northern Hemisphere. The genus has, however, only one living species, which is endemic to coastal California and the extreme southwestern corner of Oregon.

**Sequoia sempervirens** (D. Don) Endl.
*redwood (coast redwood)* *Map 77*

The first account of redwood was written by Fray Juan Crespi when the Portola Expedition encountered the species near Pinto Lake in Santa Cruz County in 1769. Archibald Menzies of the Vancouver Expedition made botanical collections near Santa Cruz in 1794, but his specimens were not formally named until 1824.

Redwood's northern range ends in the Chetco River drainage of Oregon within 14.5 miles of the State line. In California, the Redwood Forest is usually separated from the immediate coast by some combination of grassland, North Coastal Coniferous Forest, or Closed-cone Pine Forest communities. The eastern edge of the Redwood Forest merges with the Mixed Evergreen and Douglas-fir Forests. The bulk of the distribution lies below 2,000 feet in elevation.

Several redwood maps based on "commercial" forest types emphasize a gap between the more interior Eel River populations and the coastal Mendocino County stands (Forest Survey 1953, Roy 1966a). The SV survey suggests that the range narrows at this point, but the "gap" is not great. The absence of redwood from south-coastal Humboldt County is striking.

There apparently has always been a gap in redwood distribution across the low hills in southern Sonoma and northern Marin Counties. In effect the "coastal" stands in this region have been displaced eastward into Napa County. The isolated colonies east of Napa are about 42 miles from the coast. To the north the Howell Mountain stand and the Ink Grade, Swartz Creek, and Aetna Springs colonies are not quite as far from the coast. But they face the Sacramento Valley drainage and are the most "interior" localities.

In the Santa Lucia Mountains redwood is increasingly confined to steep canyon bottoms. At the heads of some of these canyons the VTM survey found some individual redwoods as high as 3,500 feet elevation. The extreme southern limit of redwood has aroused much interest. Havlik and Ketcham (1968) refute Sudworth's (1908) report of redwood in Salmon Creek. The southernmost redwood that James R. Griffin has observed, however, is only 1.5 miles from Salmon Creek. Redwoods that may have been planted exist just inside San Luis Obispo County (Hoover 1970).

Other references: Galloway 1959, Howell 1970, Oberlander 1953, Rubtzoff 1953.

## *Sequoiadendron (Sequoia)* giant sequoia

**(Taxodiaceae Taxodium Family)**

In 1939 Buchholz segregated giant sequoia from *Sequoia*. For a long time the new genus, *Sequoiadendron*, received little acceptance, but it is now coming into more general use (Munz 1959). The genus has just one living species, which is endemic to the Sierra Nevada of California.

**Sequoiadendron giganteum** (Lindl.) Buchholz
*giant sequoia, bigtree* *Map 78*

In 1850 John M. Wooster discovered giant sequoia in the Calaveras Grove (Ellsworth 1933). Public notice was aroused 2 years later when a bear hunter, Alexander T. Dowd, stumbled onto the Calaveras Grove and returned with tales of fantastic trees. Later John Bidwell "recalled" discovering these trees in 1841, but his story is not very convincing (Ellsworth 1933).

By 1853 botanical specimens were circulating in the United States and in Europe, and a confusing array of scientific names was proposed. Despite the confusion in names, the distribution of these huge trees became reasonably well known. Soon all the major groves had received names. Jepson (1910) listed seven isolated northern groves and 24 more extensive southern groves. Since then, no major discoveries have been made, but the names of the groves have become confused. Rundel (1969, 1972) reviewed the names for all the different populations and described a total of 75 groves. Little's (1971) maps do not show the isolated McKinley Grove in Fresno County.

The bulk of the distribution lies in the southern groves—a 70-mile-long zone between the Converse Basin Grove in Fresno County and the Deer Creek Grove in southern Tulare County (Fowells 1965). The species extends eastward into the Kern River drainage near Freeman and Long Meadow Creeks. The location of many of these groves seems to be associated with abundant ground water supplies (Axelrod 1959, Rundel 1969). Elevations range from a low of 2,700 feet on the South Fork of the Kaweah River below the Garfield Grove to a high of 8,800 for an outlier above the Atwell Grove (Rundel 1969). The boundaries of the present groves have been relatively stable for many centuries (Rundel 1971).

North of the Kings River the more isolated stands occur—the McKinley, Nelder, Mariposa, Merced, Tuolumne, South Calaveras, North Calaveras, and Placer groves. The Placer Grove, with six live trees and two fallen logs, grows near the Middle Fork of the American River. This extreme northern stand, known as early as 1860 (Ellsworth 1933), now includes some planted trees

Other references: Calif. Dep. Nat. Resources 1952, Hartesveldt 1965.

## *Taxus* yews

**(Taxaceae Yew Family)**

In the Northern Hemisphere about eight tree and shrub species of yews have been described. Three tree and one shrub species grow in North America. Only one yew ranges into California.

**Taxus brevifolia** Nutt.
*Pacific yew* *Map 79*

Pacific yew ranges over a large area in the West. It reaches north to Alaska and eastward to Montana. In California it is scattered, and our map shows only a fraction of the isolated stands. The small, understory yew trees seldom appear on vegetation maps. Yet in productive forests in parts of the Klamath Mountains, Cascade Range, and northern Sierra Nevada yew abounds in almost every canyon and is sprinkled on the shady uplands.

We found no yew records for Sonoma County although it may well grow there. The southern limit in the Coast Ranges is probably in Marin County (Howell 1970). Despite presistent reports of yew in the Santa Cruz Mountains (Munz 1959, Little 1971), Thomas (1961) was unable to find any evidence of native yews in that area. Some of the reports may be based on a planted yew at Loma Mar.

The southern limit in the Sierra Nevada is in the North Grove, Calaveras Big Tree State Park (Rundel 1968). No support for more southerly reports in the Sierra Nevada can be found now.

Pacific yew does not cross the Sierra Nevada. Some Shasta County yew stands are east of the main Cascade crest but are still within the Mixed Conifer Forest. Little (1956) mentions one dubious report of yew from the California-Nevada border area near the Truckee River. A 1910 specimen by Amos Heller is labeled "Morrills Lake, above Verdi, Washoe Co." Neither the yew or Morrills Lake can now be relocated.

Other references: Cooke 1940, Jepson 1910, Powell 1969, Stebbins 1968, Towsley 1937, Tracy (n/d).
Personal correspondence: Philip W. Rundel, Dec. 1969, John H. Thomas, Oct. 14, 1970.

## *Thuja* thujas (arborvitae)

**(Cupressaceae Cypress Family)**

This Northern Hemisphere genus has six species. Two widespread species grow in North America—one in the east, the other in the west. The western species ranges into California. The other four thujas grow in Asia.

**Thuja plicata** Donn
*western redcedar* *Map 80*

The range of western redcedar resembles that of western hemlock (Fowells 1965). Western redcedar has a continental distribution from southeastern British Columbia south into central Idaho. It also has a broad coastal range from the southeastern corner of Alaska down through Oregon. In western Oregon and Washington *Thuja plicata* is common in both "*Tsuga heterophylla*" and "*Abies amabilis* zones" (Franklin and Dyrness 1969).

California's *Thuja* stands are just a minor southern extension of the main distribution. This tree is common in the North Coastal Coniferous Forest only in the lower Mad River drainage and the very wet region south of Ferndale in Humboldt County. Unlike western hemlock and Sitka spruce, *Thuja plicata* does not have any disjunct stands in coastal Mendocino County. Sudworth's (1908) Mendocino report must be in error.

Although our data are incomplete, western redcedar does not seem to be common in northern Humboldt or Del Norte Counties. Some of the isolated stands in this region are in rather boggy habitats. The most inland colony we know of is at Sanger Lake.

## *Torreya* torreyas

**(Taxaceae Yew Family)**

This Northern Hemisphere genus has only six species. Two species occur in North America, one confined to a small area in Florida and Georgia, and the other endemic to California.

**Torreya california** Torr.
*California torreya (California-nutmeg)* *Map 81*

No other tree in California has a distribution pattern quite like torreya. Its range has two distinct parts, one in the Coast Ranges and the other in the Cascade-Sierra Nevada foothills. What is unusual is the lack of any sort of connection between the two parts—across either the north or south.

This California endemic is not really rare. As Jepson (1923) stated, the range is fairly extensive but localities are few in number and trees few in a given locality. It was first collected in the Sierra Nevada by William Lobb in 1851.

The most northerly record we could find in the Coast Ranges is in the southwestern corner of Trinity County (at the Island Mountain railroad tunnel). The main distribution starts in central Mendocino County (Jepson 1910). We have probably shown only a small portion of the isolated localities in this area. In the coastal forests torreyas are often scattered as individual trees. In Lake County torreyas also appear as chaparral shrubs. Part of the Santa Cruz Mountain distribution is also shrubby on sterile chaparral slopes. Sharsmith (1940) and the VTM survey both found a few trees in the Mount Hamilton Range. The southern end of the Coast Range

distribution is on Fremonts Peak, Monterey County (Howitt and Howell 1964). The interior outpost in the Coast Ranges is Walker Ridge, Colusa County, on serpentine soil.

In the Cascade-Sierra Nevada foothills torreya is usually confined to shady canyon bottoms and seldom occurs in open chaparral. Mallory et al. (1965) found the extreme northern stand on the North Fork of Battle Creek in Shasta County. Torreya is common along many creeks in eastern Tehama County. The southern limit is probably on the Tule River in Tulare County (Jepson 1923). The elevational range in the southern Sierra Nevada runs from 3,000 to almost 7,000 feet.

Other references: Griffin and Powell 1971, Howell 1970, Thomas 1961, Towsley 1937.
Personal correspondence: Philip W. Rundel, Dec. 1969, Donald V. Hemphill, Oct. 15, 1970.

## *Tsuga* hemlocks

**(Pinaceae Pine Family)**

The genus *Tsuga* has about 10 species in the Northern Hemisphere, four in North America and the others in Asia. Two species range into California. French taxonomists have described several hemlock species and hybrids that are not generally recognized in the United States.

**Tsuga heterophylla** (Raf.) Sarg.
*western hemlock* *Map 82*

Continental populations of western hemlock range from southwestern British Columbia south into central Idaho (Fowells 1965). The broad coastal distribution starts in the north on the Kenai Peninsula of Alaska. In western Washington and Oregon the "*Tsuga heterophylla* zone" is the most extensive vegetation type (Franklin and Dyrness 1969).

California is at the southern margin of this large distribution. Western hemlock is locally common as far south as the lower Mad River drainage in Humboldt County. It usually appears as a minor component in the North Coastal Conifer Forest and the Redwood Forest. Sudworth (1908) knew of no California stands more than 20 miles from the coast. The SV survey, however, mapped western hemlock east of Weitchpec —some 30 miles inland. Near Bear Basin Butte in eastern Del Norte County an outpost of western hemlock grows within a mile or two of mountain hemlock.

Western hemlock is absent south of the Eel River in Humboldt County but reappears in coastal Mendocino County. The southern limit is probably in the Gualala River region of Sonoma County (Jepson 1923, Powell 1968). Early reports of western hemlock in Marin County cannot be confirmed (Jepson 1910, Howell 1970).

**Tsuga mertensiana** (Bong.) Carr.
*mountain hemlock* *Map 83*

Mountain hemlock has a continental distribution in southeastern British Columbia, western Montana, and northern Idaho (Fowells 1965). Its coastal distribution extends north to the Kenai Peninsula of Alaska. South of the Canadian border in the Cascades, mountain hemlock no longer grows at lower elevations. In the western portions of Washington and Oregon the "*Tsuga mertensiana* zone" is the highest forested zone (Franklin and Dyrness 1969).

In California, mountain hemlock is an important species in the Subalpine Forest. It is locally abundant in the Klamath Mountains. In the western Siskiyous along the Del Norte-Siskiyou County line mountain hemlock drops to relatively low elevations—4,000 feet on Bear Basin Butte. The southern outpost in the Klamath region is probably a tiny colony on Black Rock Mountain near North Yolla Bolly.

Mountain hemlock is not widespread in the California Cascades. It occurs on Mount Shasta (Cooke 1940). Probably additional small stands are scattered in eastern Siskiyou County, for which we have no vegetation type data. In Shasta County mountain hemlock grows on Magee Peak. In the nearby Latour State Forest a few trees grow as low as 6,000 feet. Mountain hemlock is again common in the Lassen Peak region between 7,500 and 9,200 feet in elevation (Gillett, Howell, and Leschke 1961).

The main Sierra Nevada population starts in Sierra County and runs almost continuously in the Subalpine Forest into Fresno County. In the southern Sierra Nevada, mountain hemlock ranges in elevation up to 11,600 feet (Raven 1950-1953). The extreme southern limit seems to be near Silliman Lake in Tulare County. Probably more mountain hemlock colonies occur on the eastern slope of the Sierra Nevada than the map shows. Sudworth's (1908) report of mountain hemlock in the San Jacinto Mountains of southern California is unconfirmed.

Other references: Howell 1940-42, Klyver 1931, Maciolek and Tunzi 1968, Parsons 1968, Raven 1950-53, Rockwell and Stocking 1969, Sawyer and Thornburgh 1969.

## *Umbellularia* California-laurel

**(Lauraceae Laurel Family)**

This genus is rather geographically isolated from its relatives. *Umbellularia* has only one species, and it is the only genus in the Laurel Family found in the western United States. Eight genera of this family occur in the eastern part of the country.

**Umbellularia californica** (Hook. & Arn.) Nutt.
*California-laurel, California-bay (pepperwood, Oregon-myrtle)* *Map 84*

California-laurel ranges from the Umpqua region of southwestern Oregon south to San Diego County (Fowells 1965). It was first collected by Archibald Menzies of the Vancouver

expedition of 1790-92 between Monterey and San Francisco. This species grows abundantly, in a variety of tree and shrub forms, in the western Klamath and north Coast Ranges. In the Redwood and Douglas-fir Forests, California-laurel trees are conspicuous on valley bottomlands and near foothill streams. Some of the finest groves in California used to grow in the lower Eel River Valley (Jepson 1910). South of the Santa Lucia Mountains California-laurel becomes less common and more widely scattered. Individual trees may still be large; for example, the "Laurel of San Marcos" near Santa Barbara is 6 feet in diameter (Van Rensselaer 1948). The last outpost in southern California seems to be on the eastern slope of the Laguna Mountains, south of Jepson's (1910) Julian report.

Much of the inner Coast Range and Sierra Nevada distribution occurs in chaparral areas below the Mixed Conifer Forest. Dense thickets are common on the steep lava rims of eastern Tehama County. The Sierra Nevada populations seldom exceed 5,000 feet in elevation. They extend as far south as Breckenridge Mountain in Kern County (Twisselmann 1967).

Shrubby forms are locally abundant on serpentine soils in both Coast Range and Sierra Nevada foothills. The place name "pepperwood springs" has been applied to such serpentine colonies in several regions.

Other references: Boughey 1968, Grinnell 1908, Howell 1970, Howell, Raven, and Rubtzoff 1958, Klyver 1931, Lewis and Gause 1966, McClintock and Knight 1968, Meyer 1931, Rockwell and Stocking 1969.

## SUMMARY


Griffin, James R., and William B. Critchfield
1972. **The distribution of forest trees in California.** Berkeley, Calif. Pacific SW. Forest & Range Exp. Stn., 114 p., illus. (USDA Forest Serv. Res. Paper PSW-82)

*Oxford:* 181.1:174.7(794) + 181.1:176.1(794).
*Retrieval Terms:* forest trees; natural distribution; phytogeography; plant communities; forest ecology; California.

The distribution of 86 forest and woodland trees native to California is illustrated on maps at a common scale. For species of limited range, large-scale inserts show greater detail of distribution. In areas where distribution data are incomplete, probable range boundaries are shown.

The maps are based primarily on the original field records of the Vegetation Type Map survey of the 1930's and secondarily on field records of the current State Cooperative Soil-Vegetation survey. These sources are supplemented by herbarium specimens, literature citations, Forest Survey plot records, personal observations, and interviews with local authorities.

Descriptive notes relate the distribution of each species to its ecological context, including the plant communities in which the tree commonly appears and the extremes of its elevational range. Taxonomic problems and possible hybridization influences are discussed. Historical items relating to the discovery of endemic species are noted. Nearly one-fourth of the species illustrated are endemic to California, and the distribution of many others is centered in the State.


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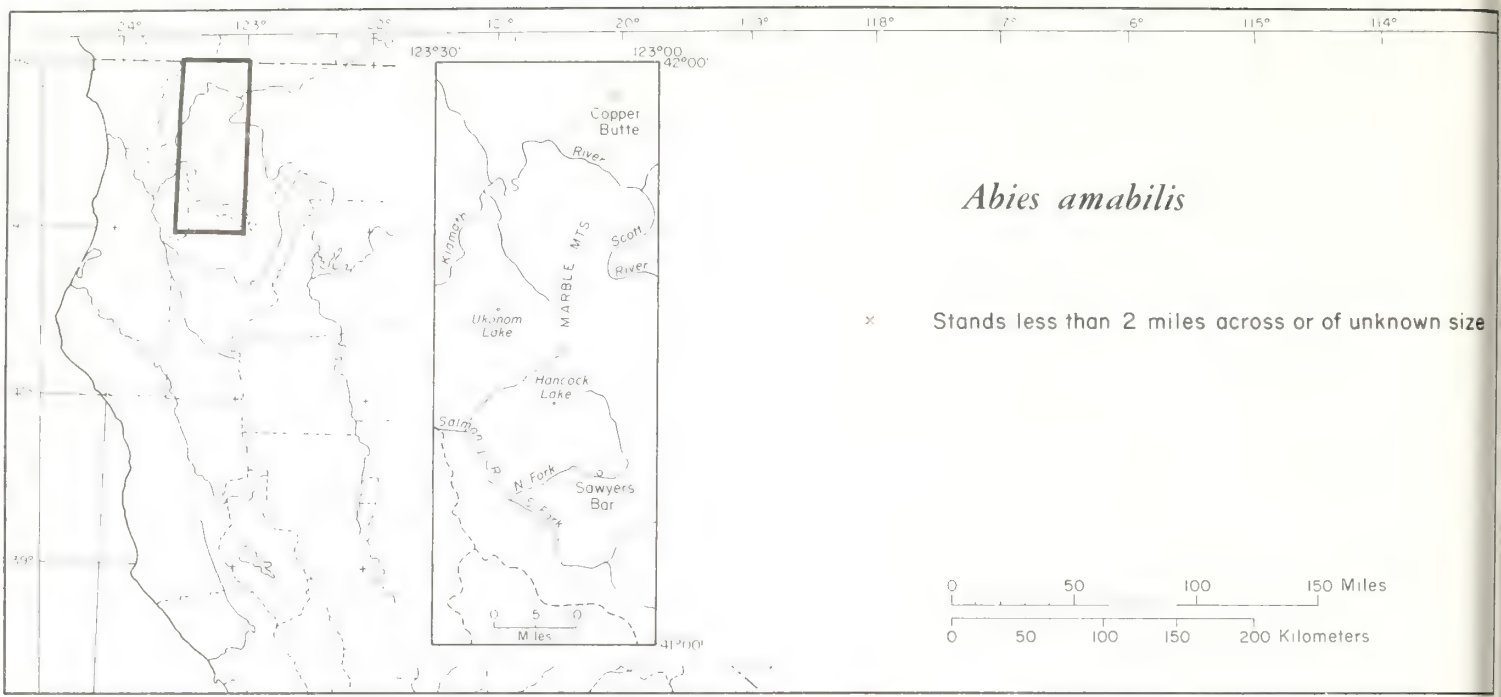
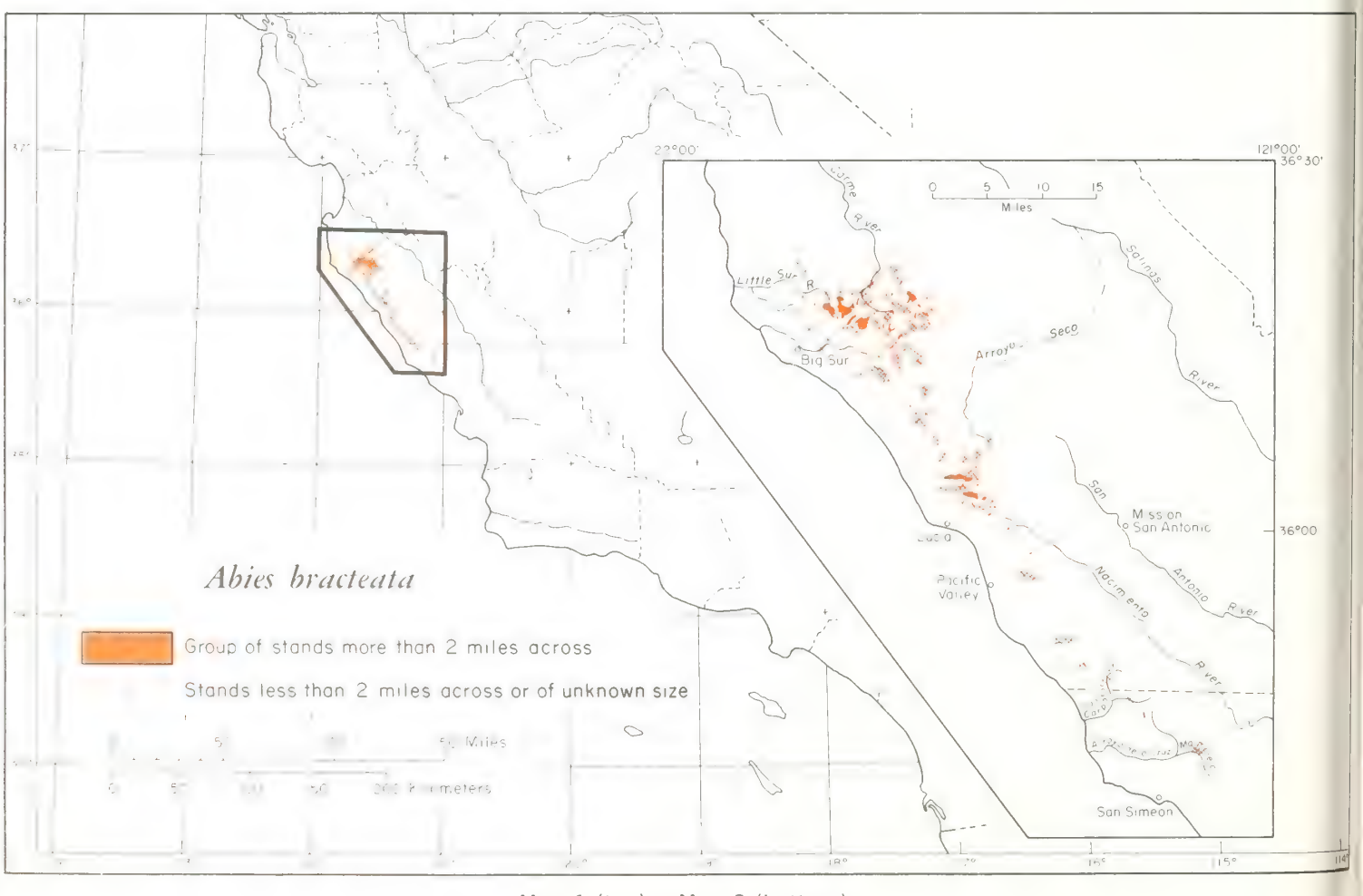
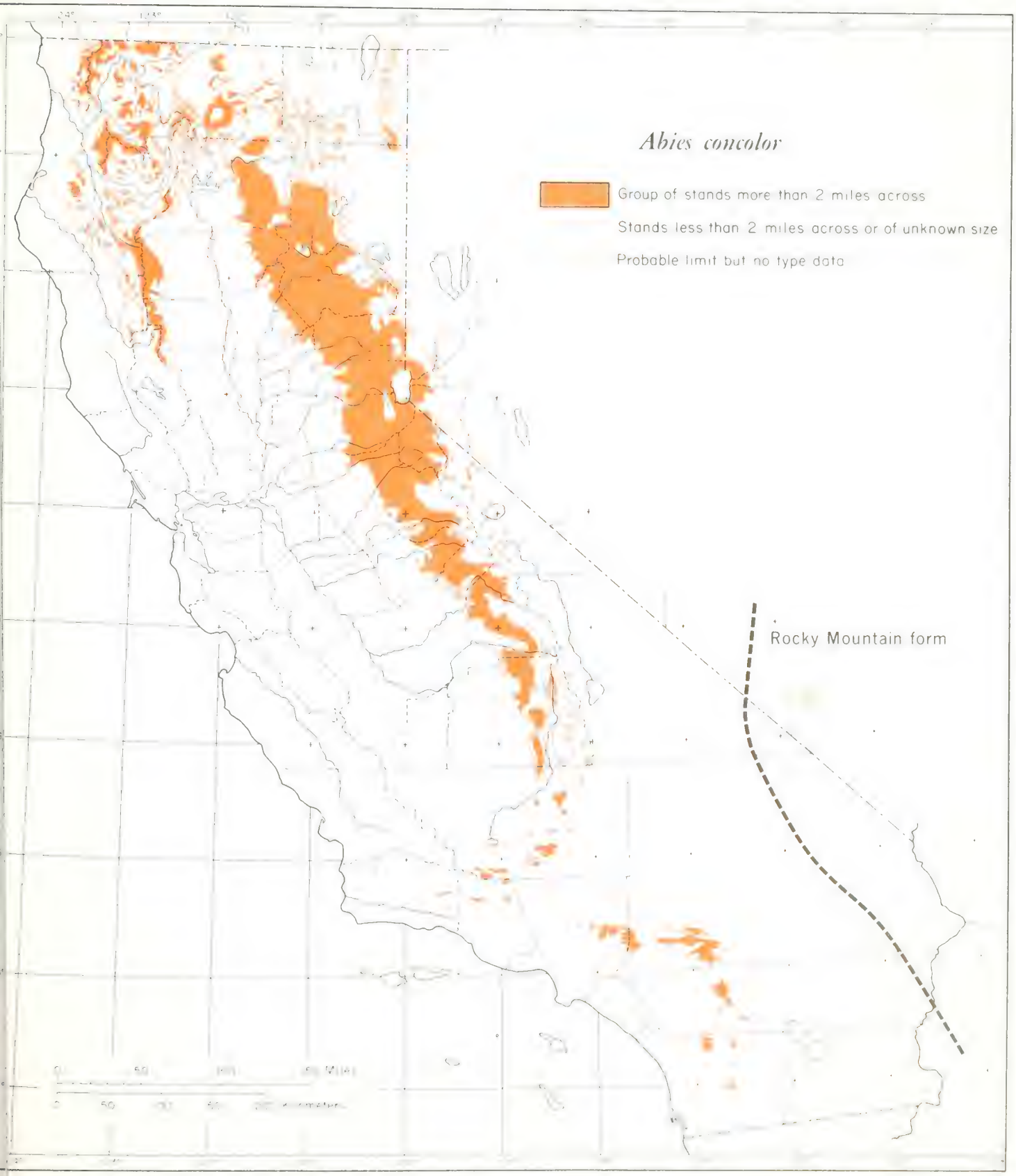
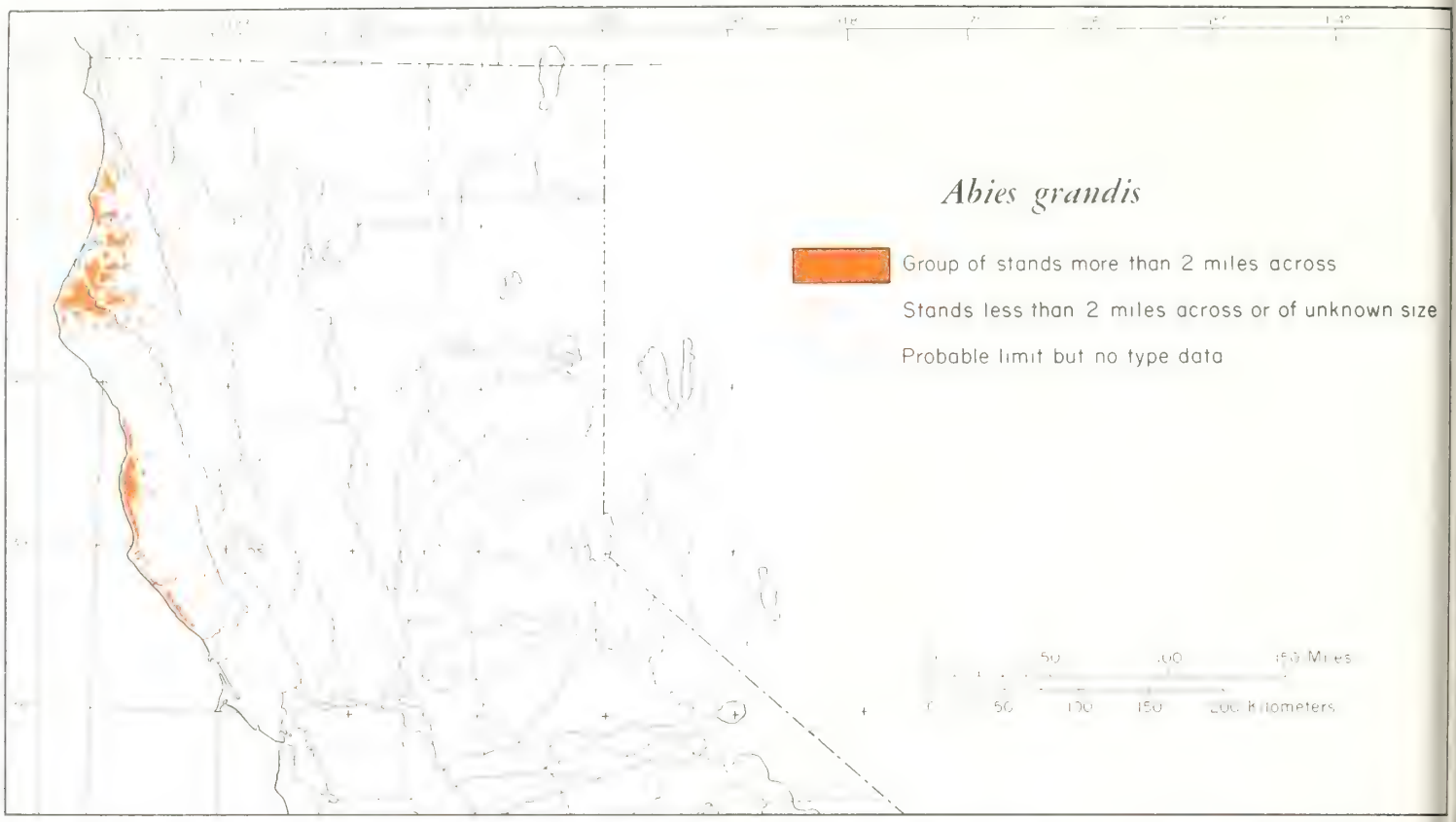


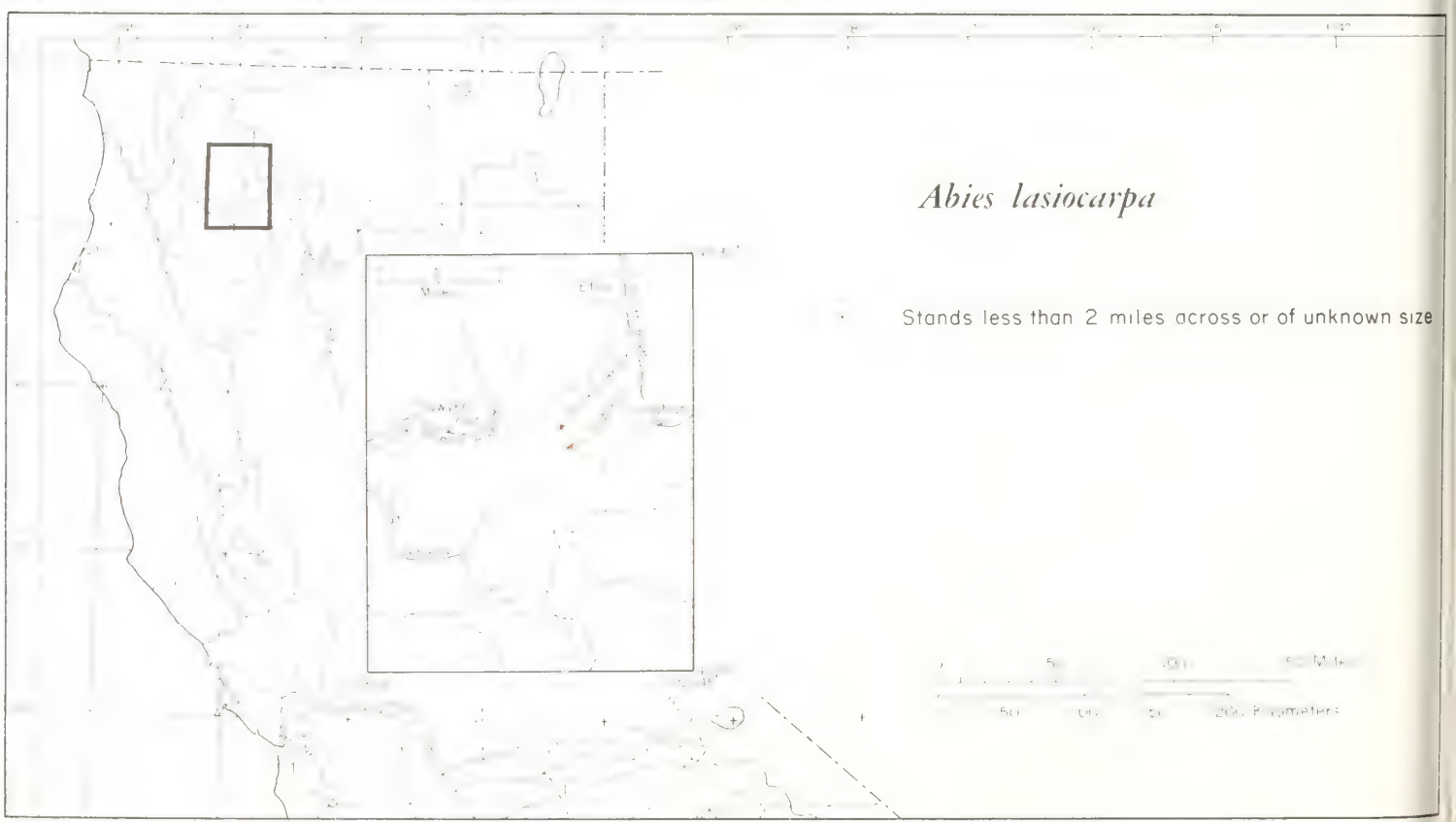




Map 1 (top) Map 2 (bottom)


*Abies concolor*
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data
Rocky Mountain form

Map 3

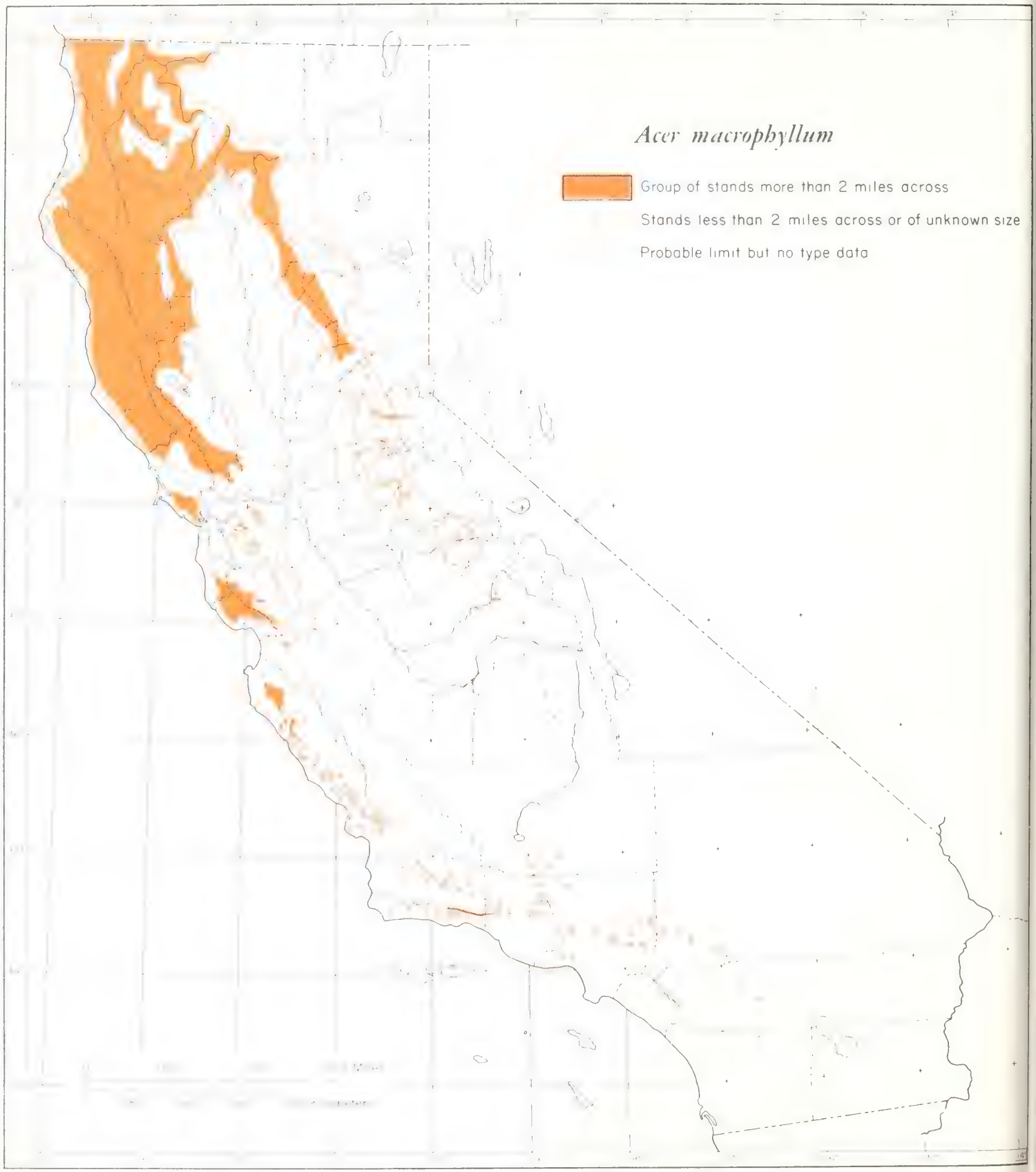


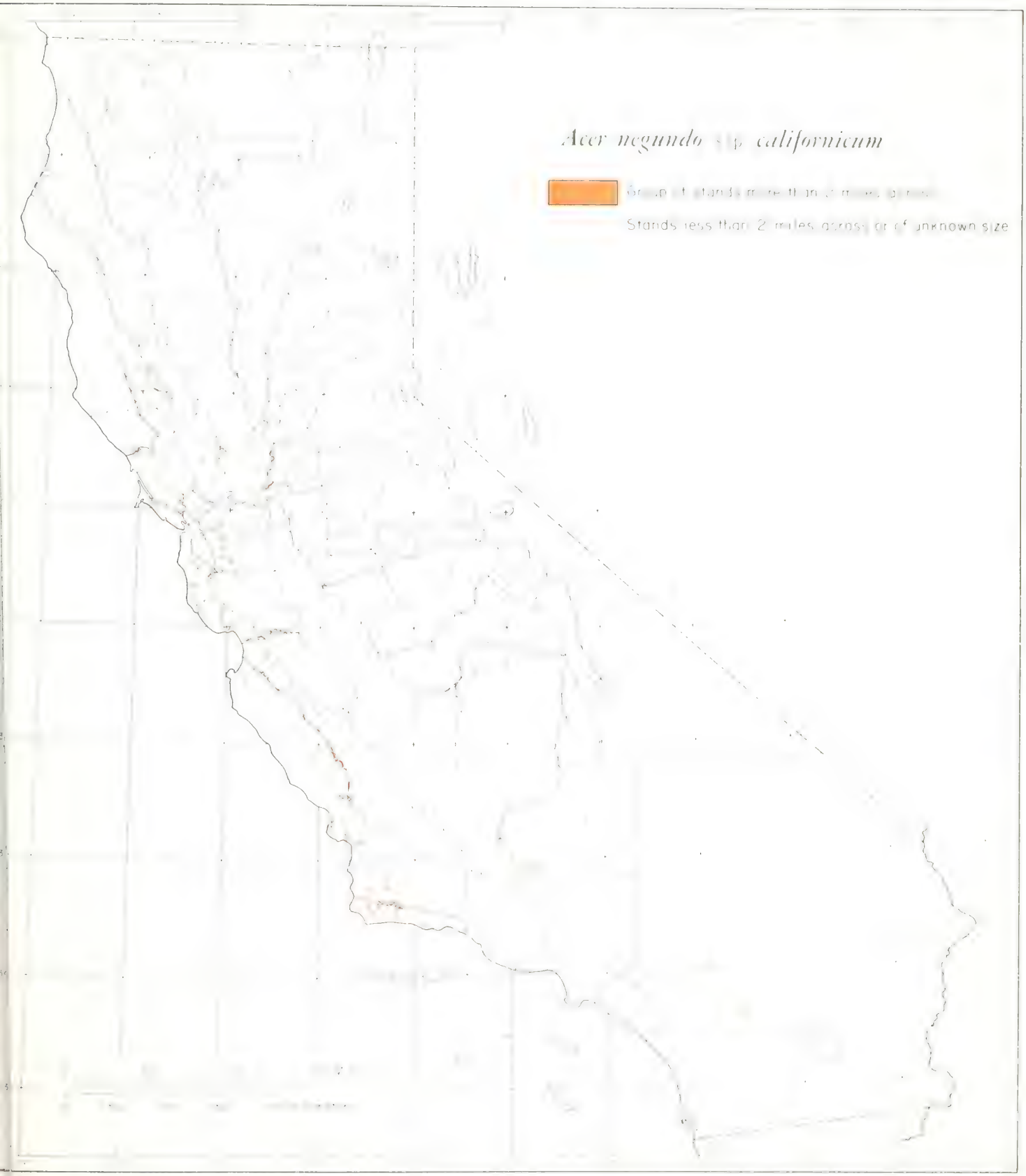

Map 4 (top)  Map 5 (bottom)

A. procera
A. magnifica
Abies procera & Abies magnifica
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data

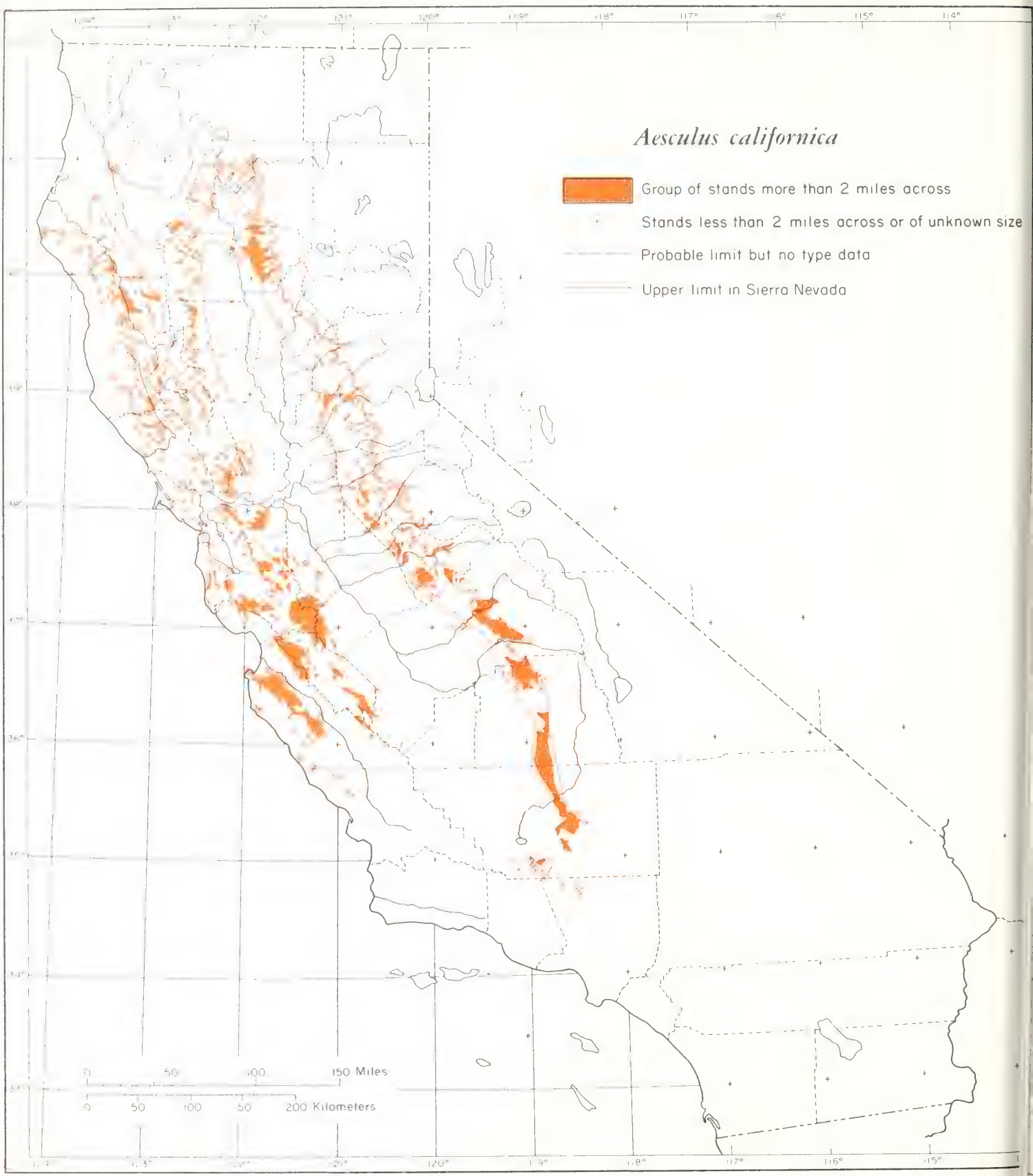
Map 6


Acer macrophyllum
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data

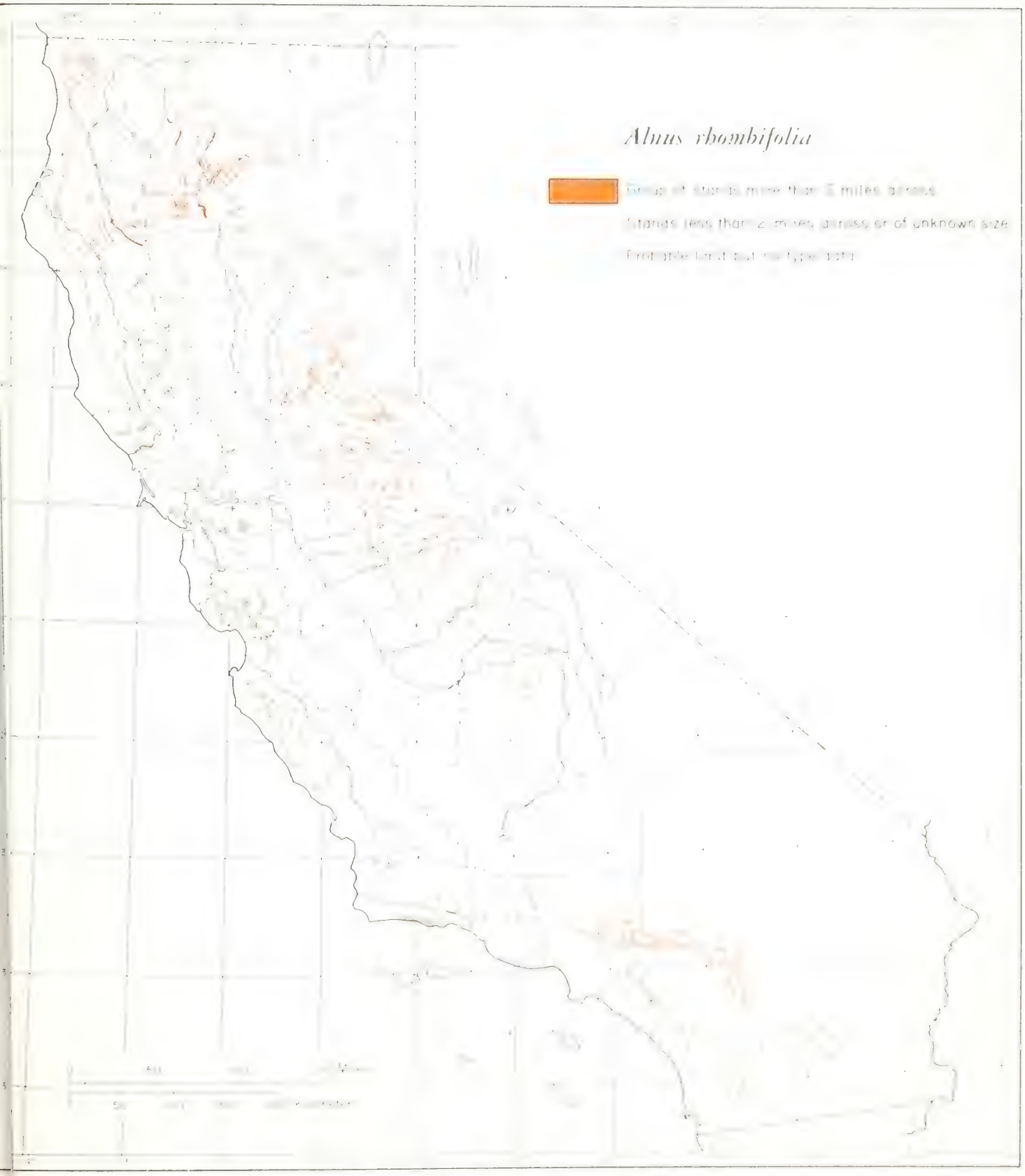
Map 7


Acer negundo ssp. californicum
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size

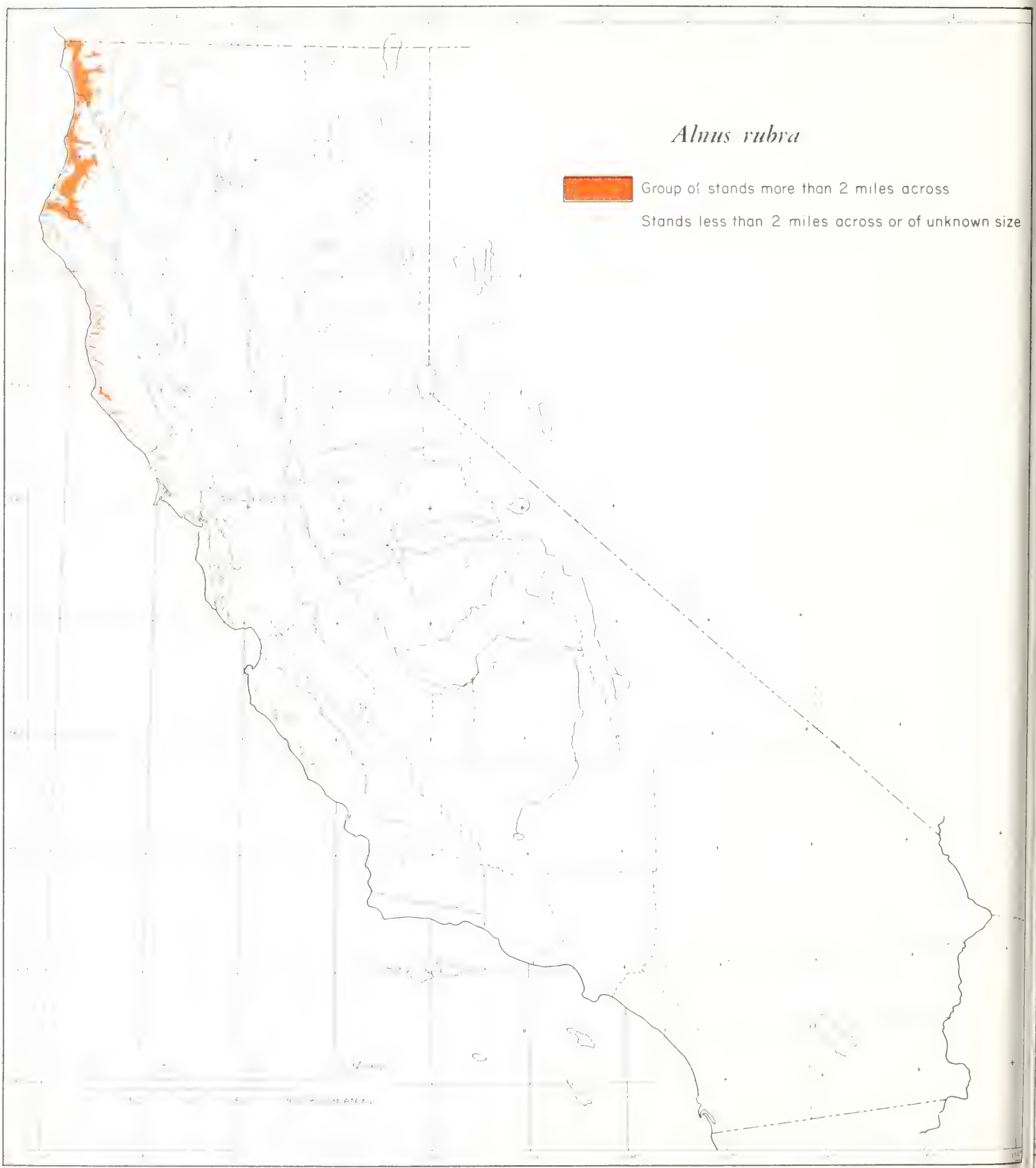
Map 8


Aesculus californica
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data
Upper limit in Sierra Nevada
0 50 100 150 Miles
0 50 100 50 200 Kilometers

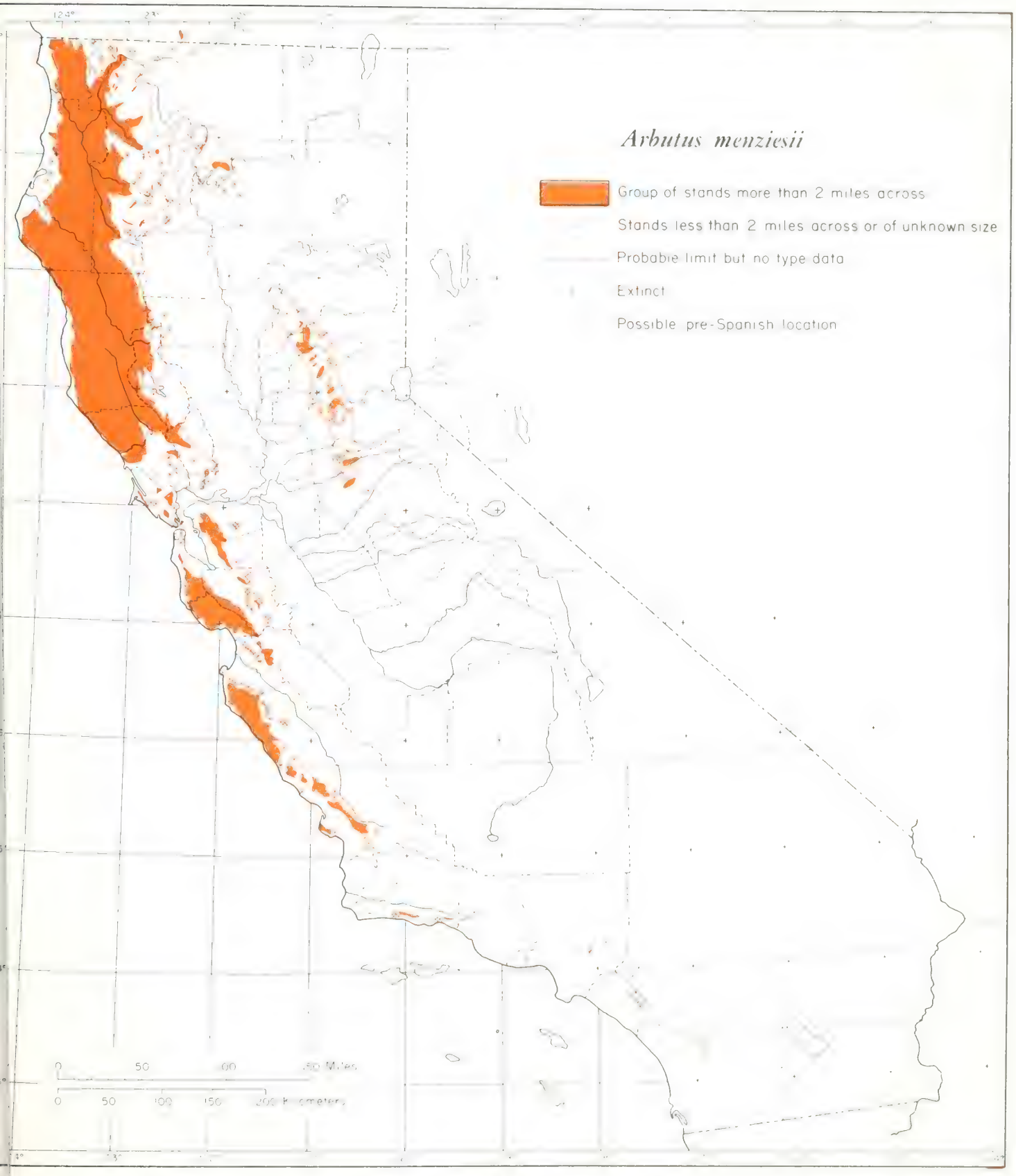
Map 9


Alnus rhombifolia
Groups of stands more than 5 miles across
Stands less than 2 miles across or of unknown size
Probable land but no type data

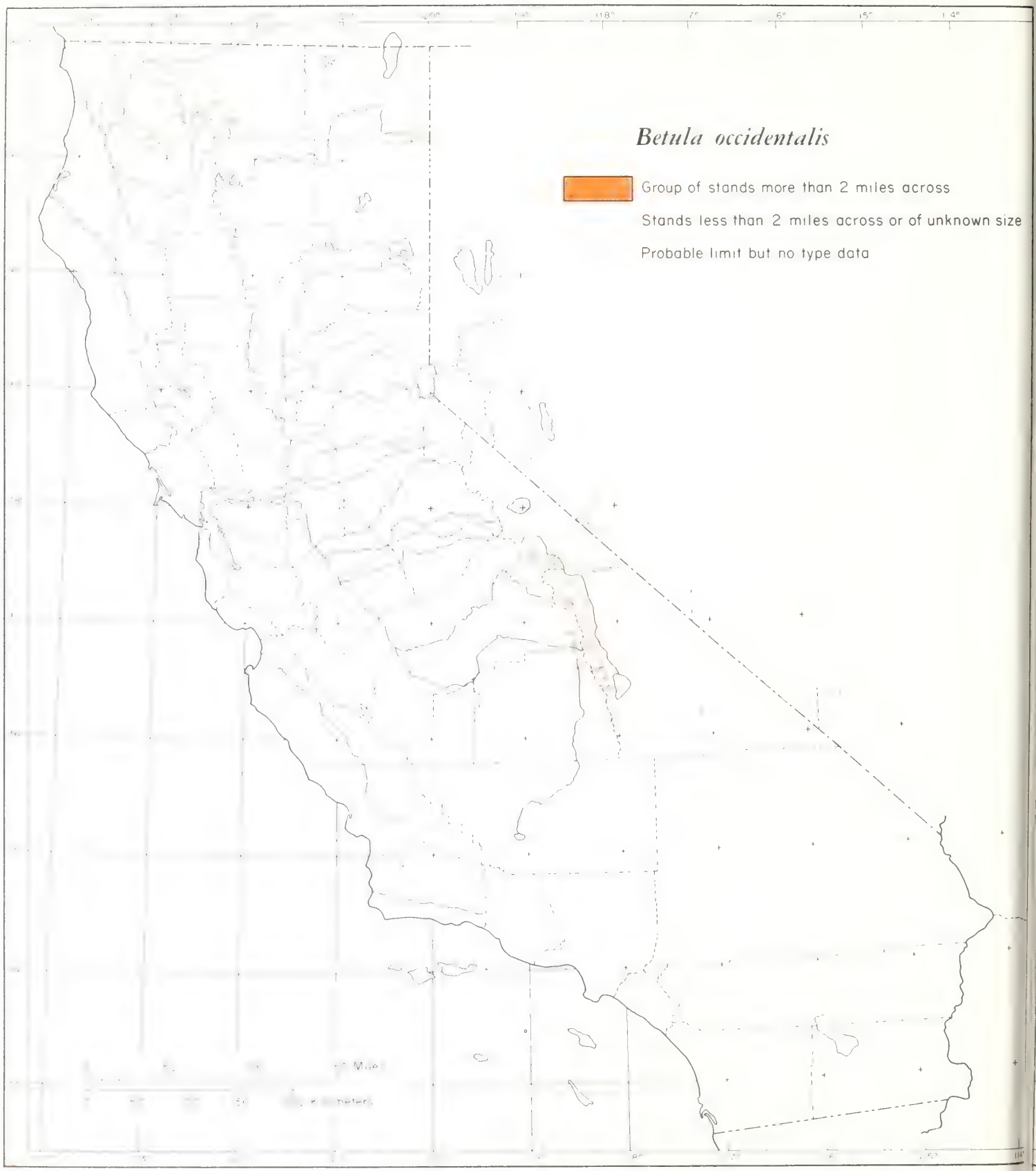
Map 16


Alnus rubra
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size

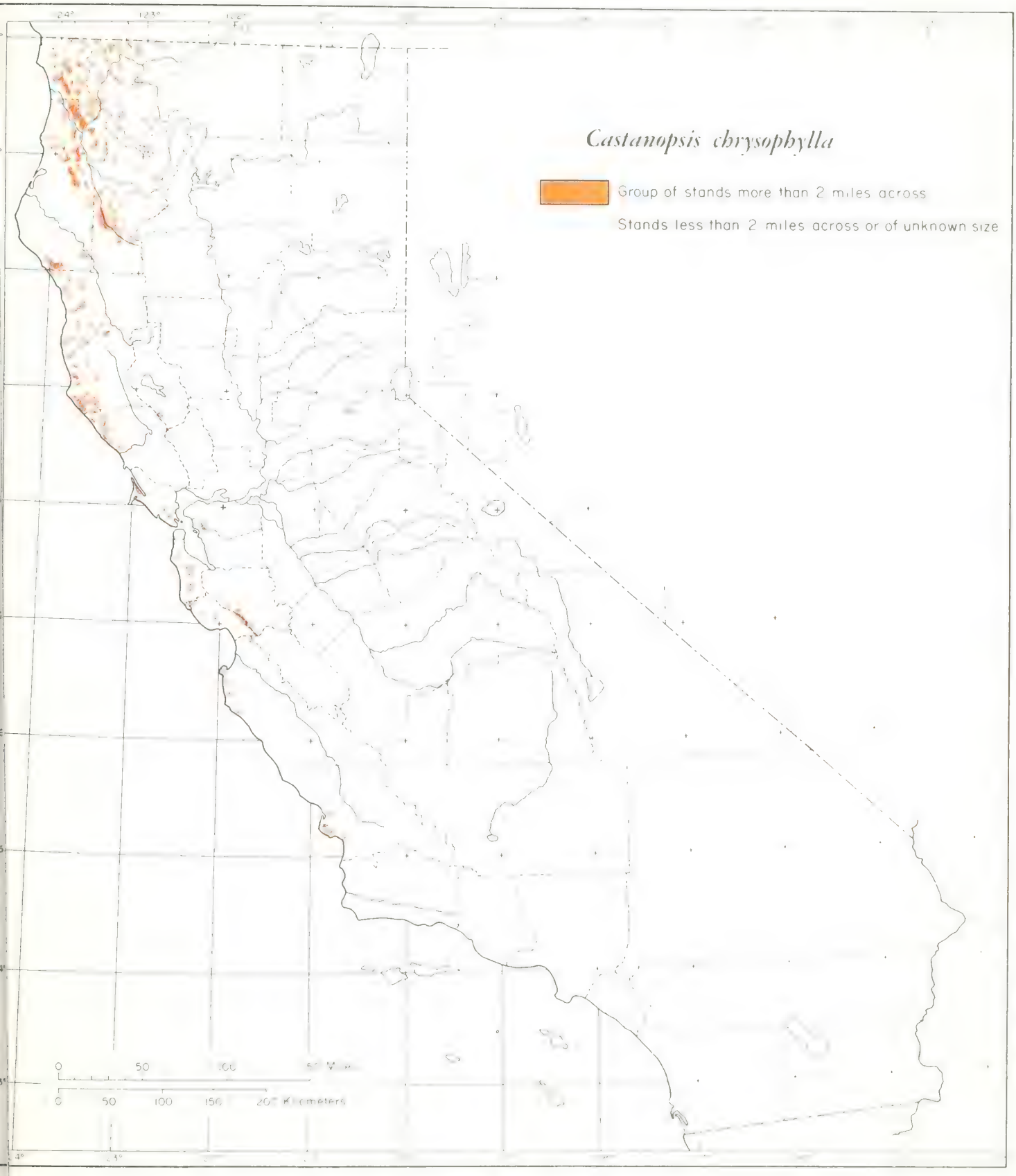
Map 11


Arbutus menziesii
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data
Extinct
Possible pre-Spanish location
0 50 100 150 Miles
0 50 100 150 200 Kilometers

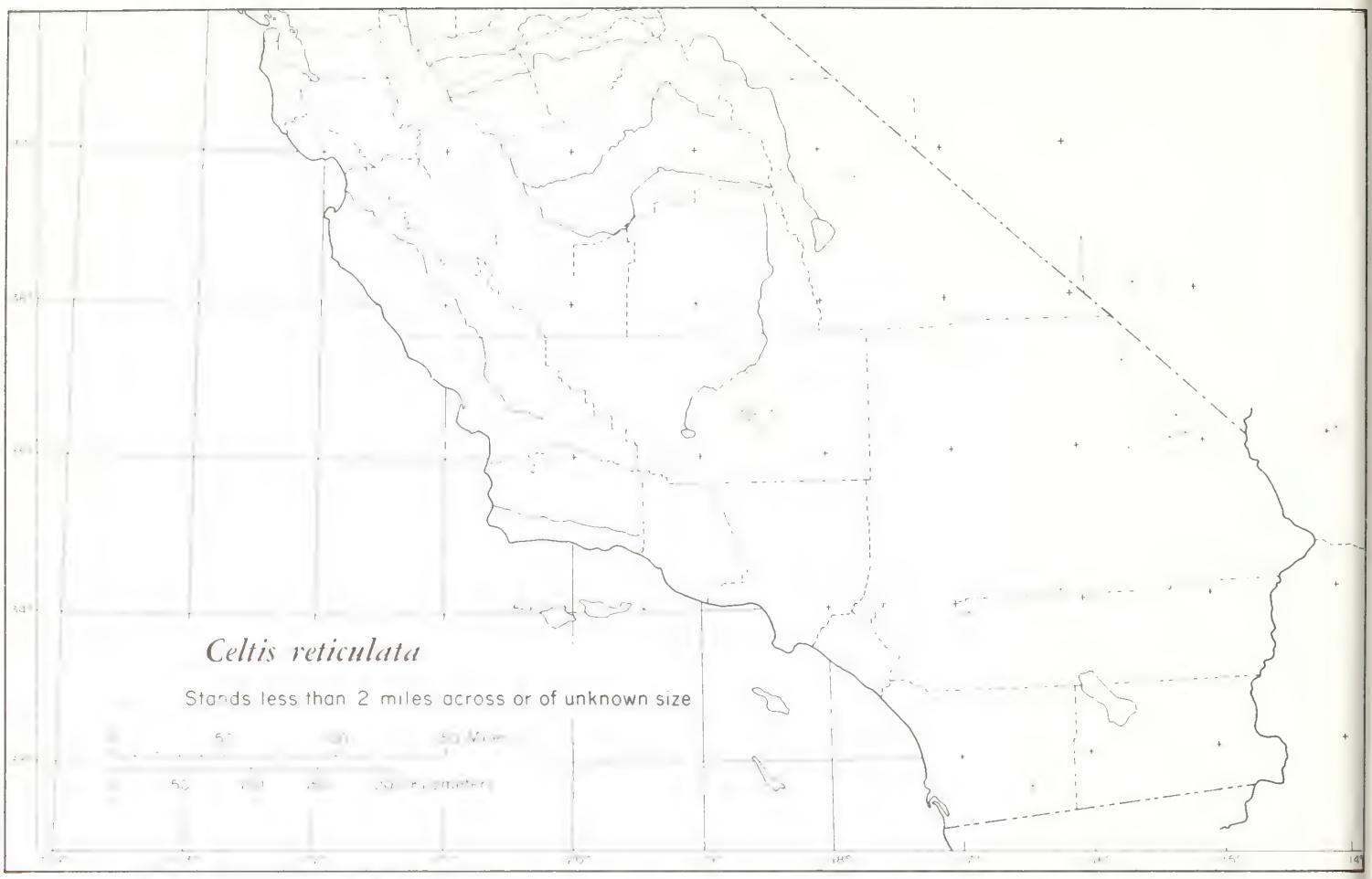
Map 12

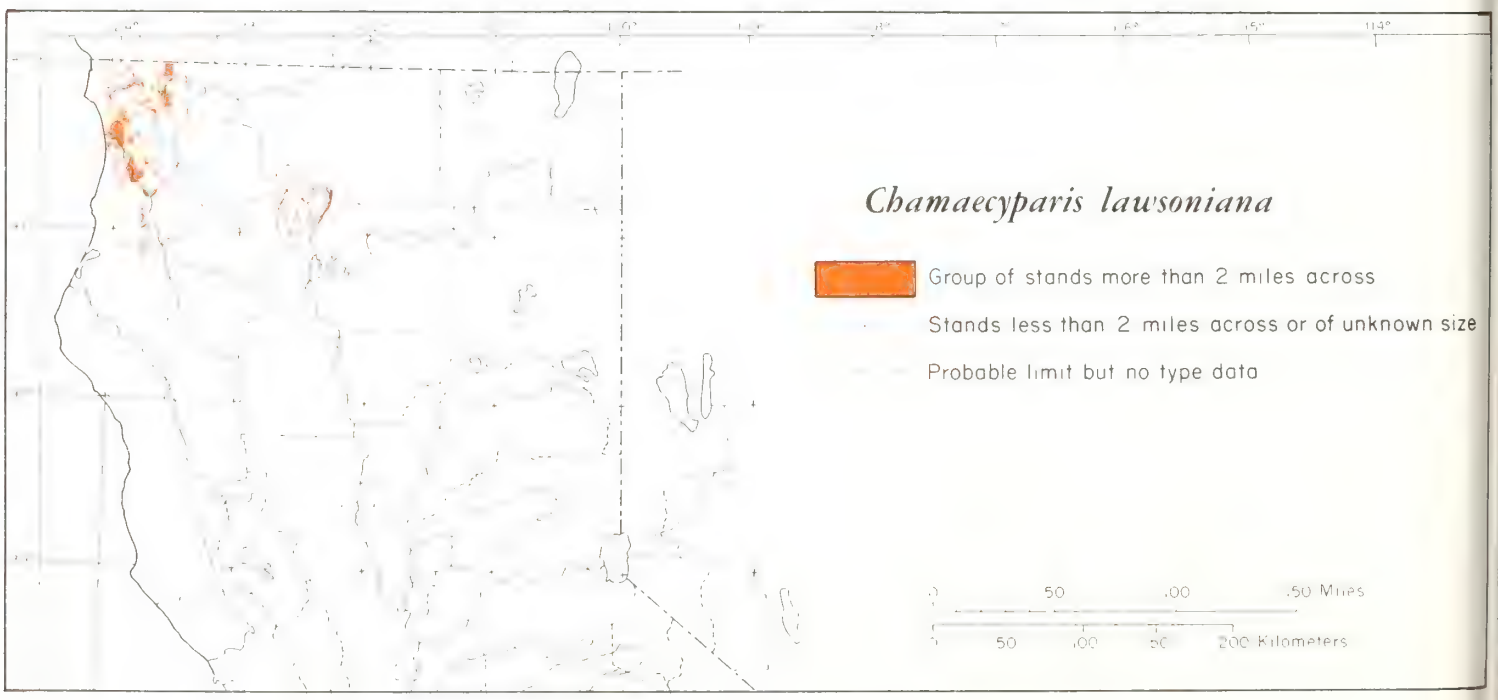

Betula occidentalis
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data

Map 13

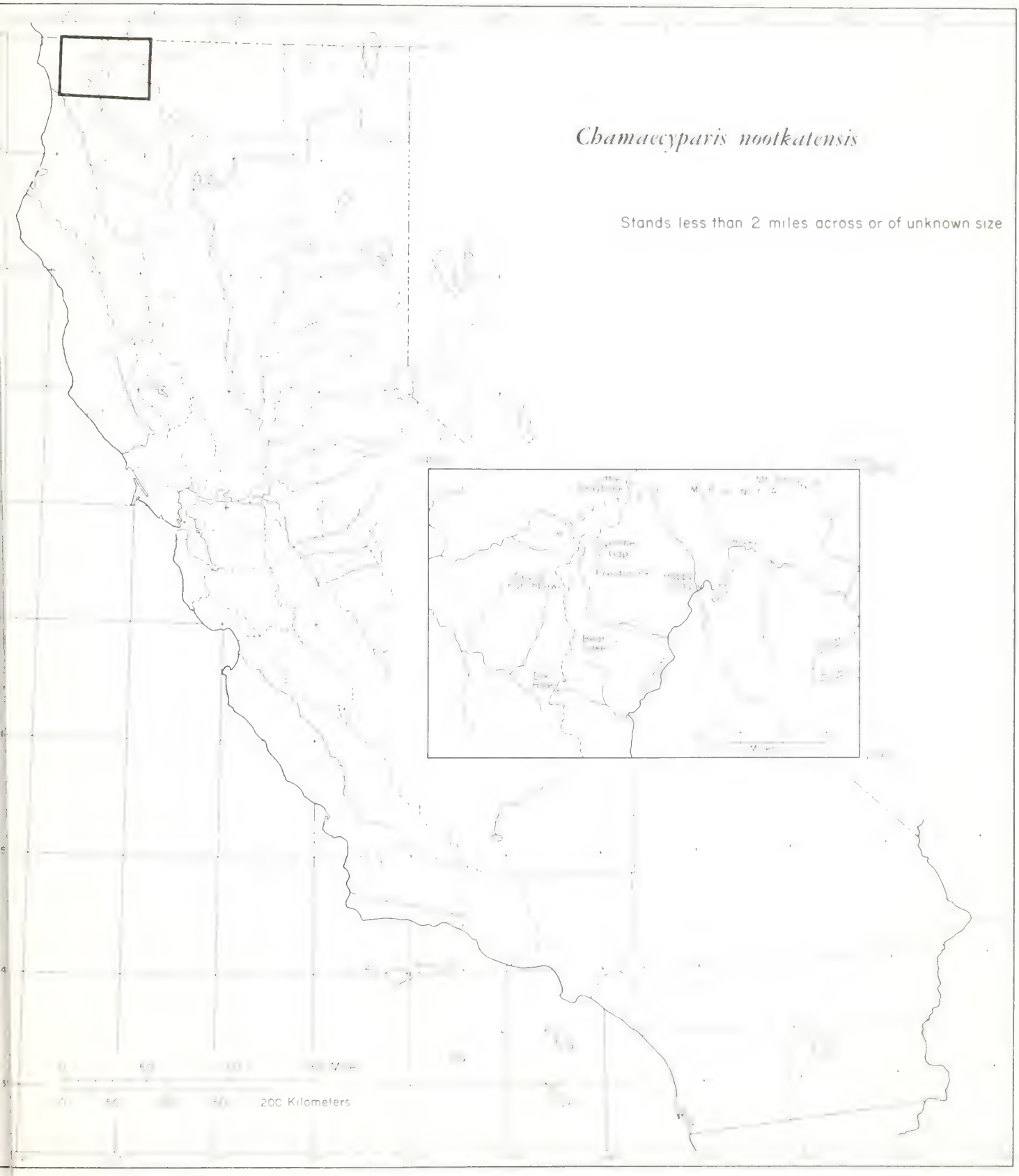

Castanopsis chrysophylla
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
0 50 100
0 50 100 150 200 Kilometers

Map 14

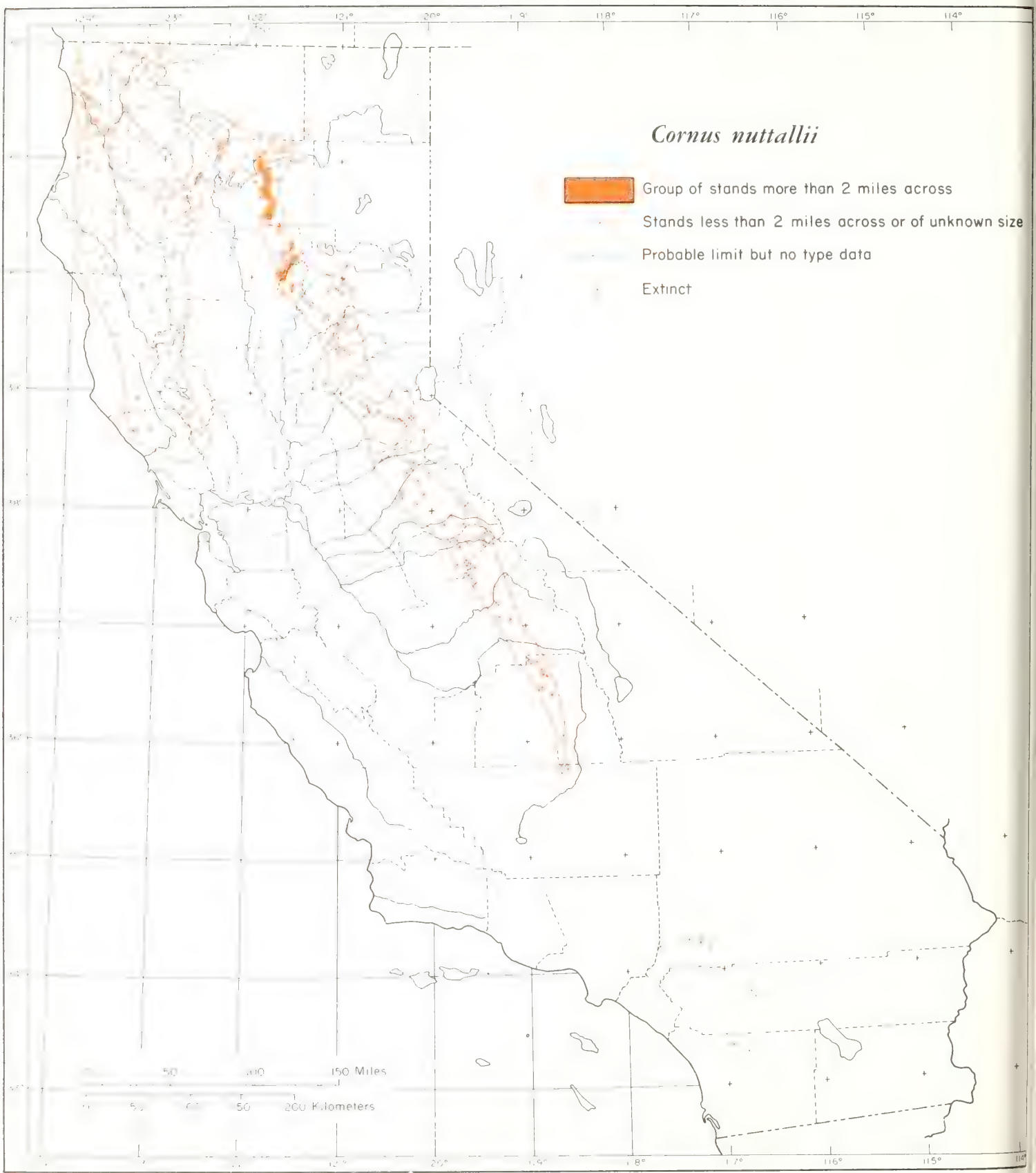


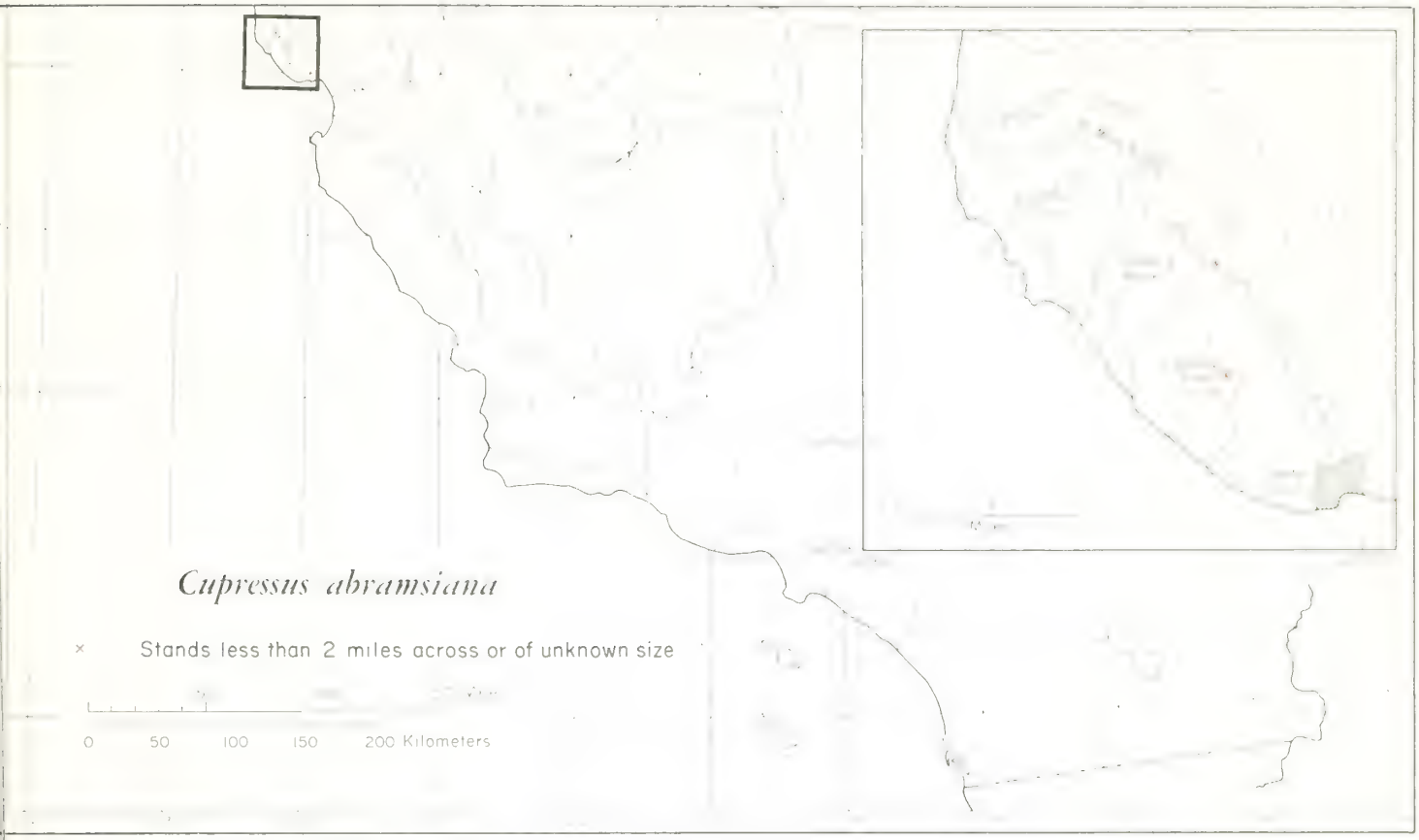

Map 15 (top)  Map 16 (bottom)

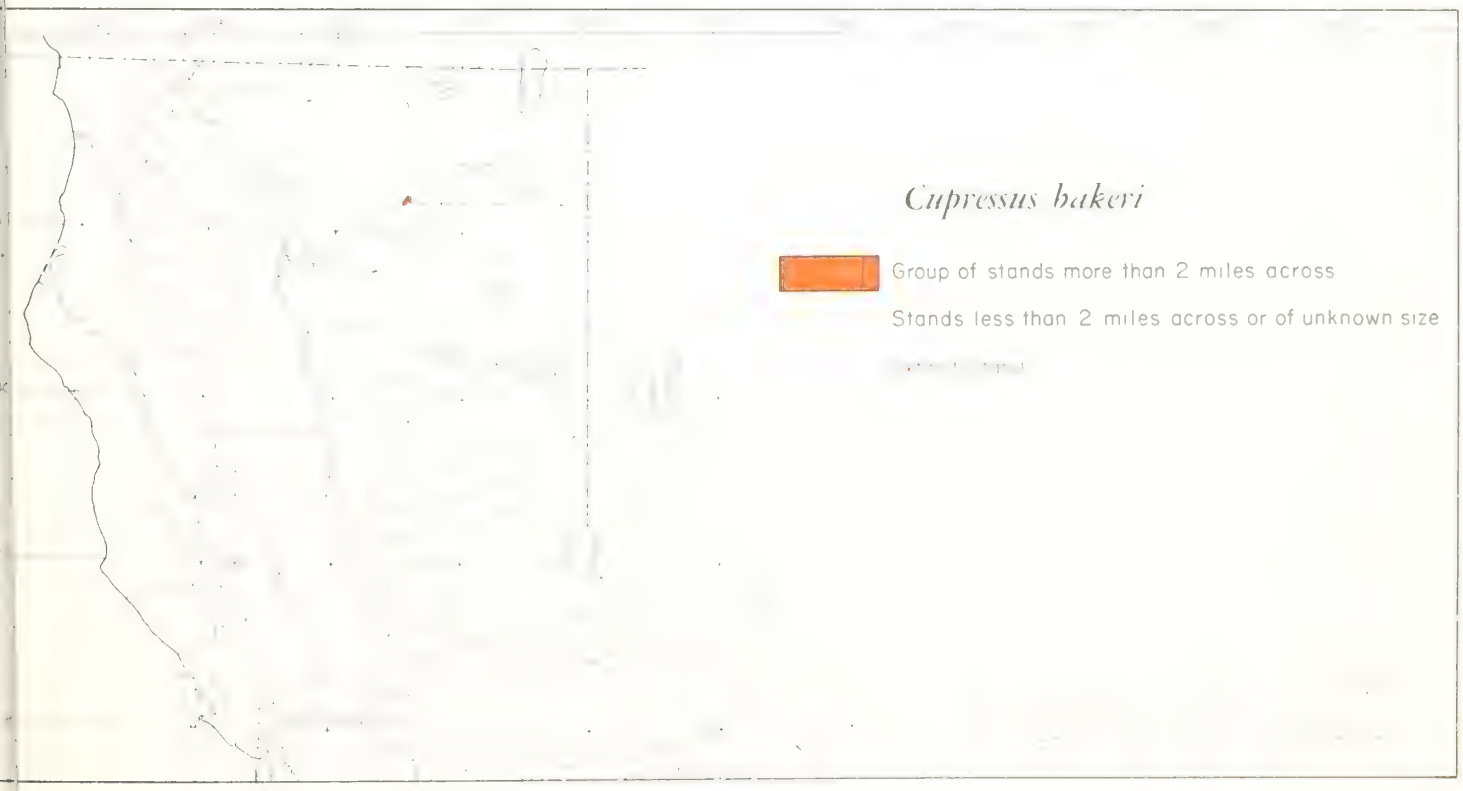

*Chamaecyparis nootkatensis*
Stands less than 2 miles across or of unknown size
200 Kilometers

Map 17

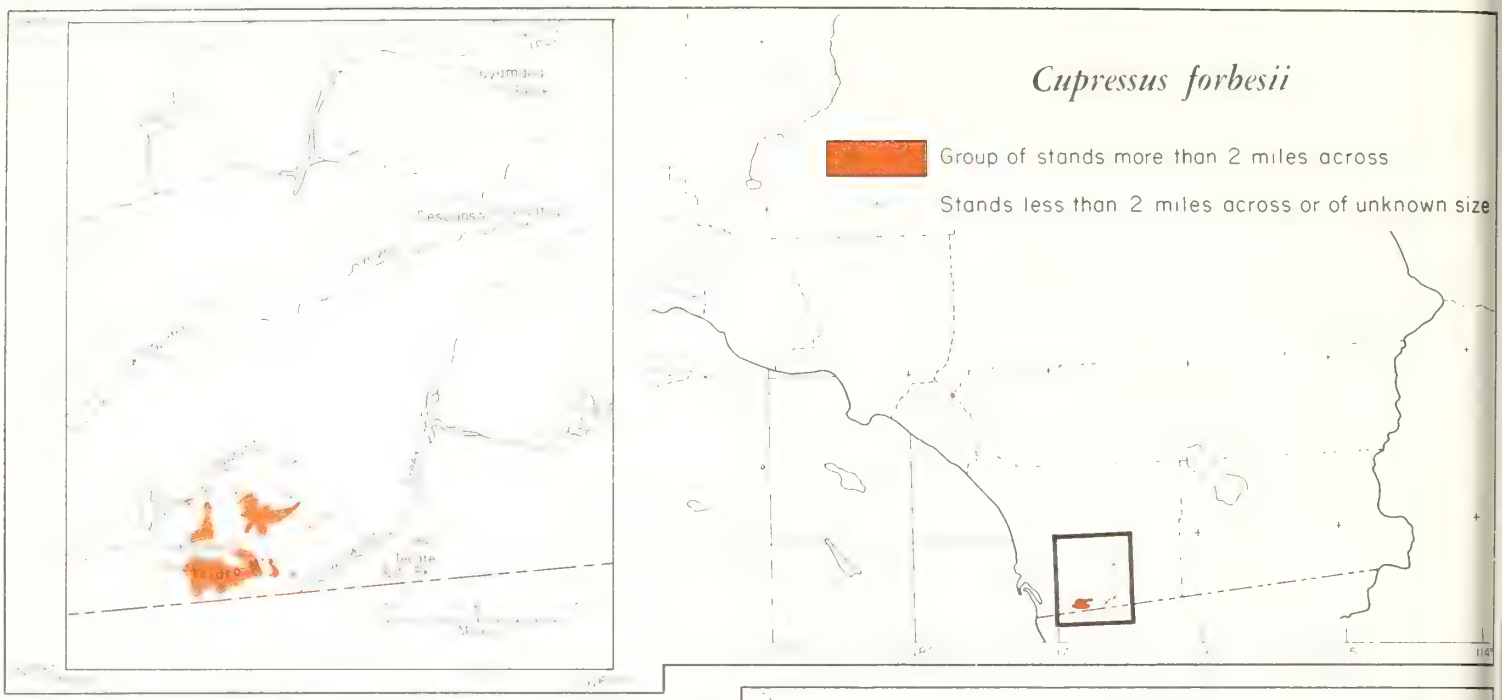

Cornus nuttallii
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data
Extinct
50
100
150 Miles
50
200 Kilometers

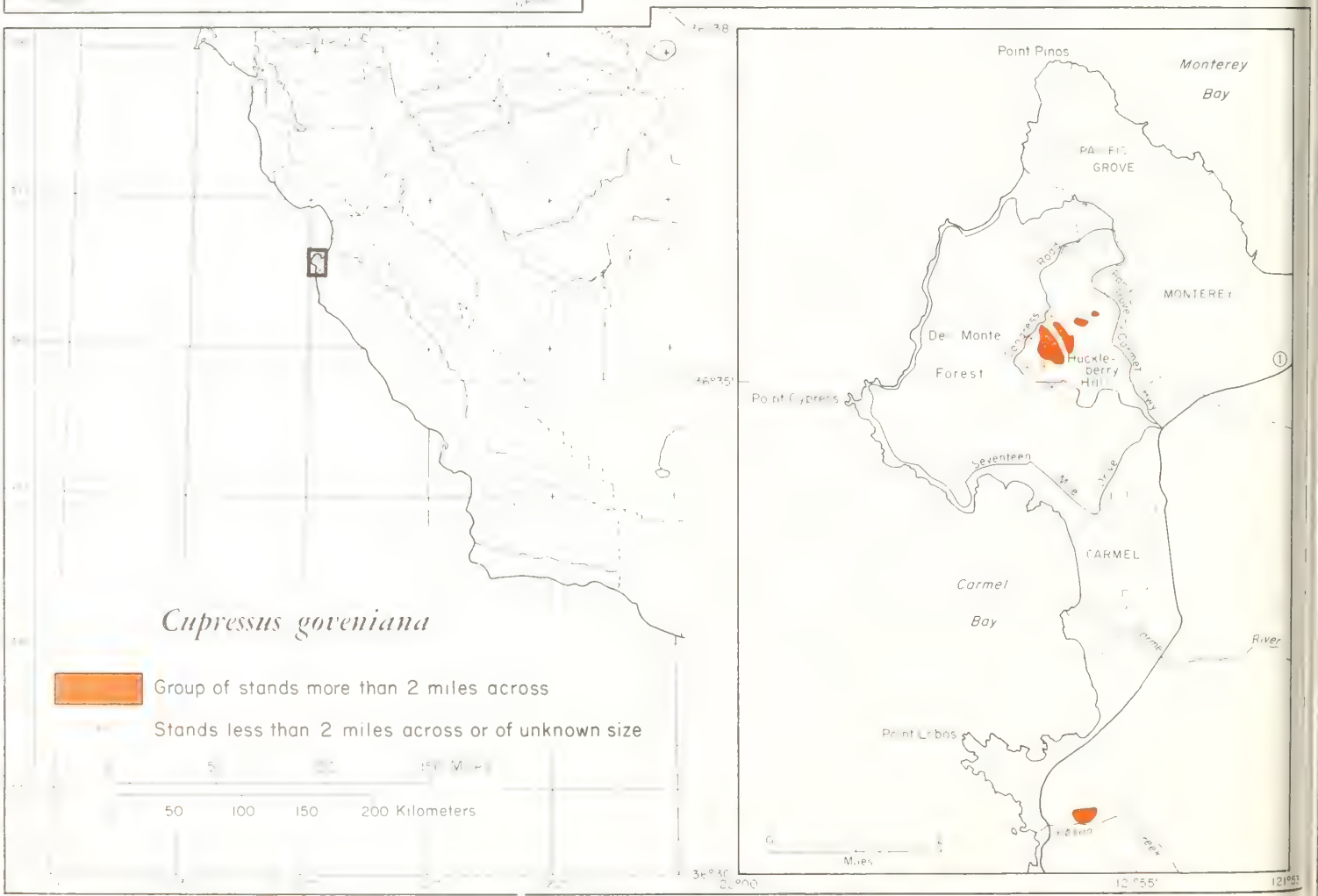
Map 18



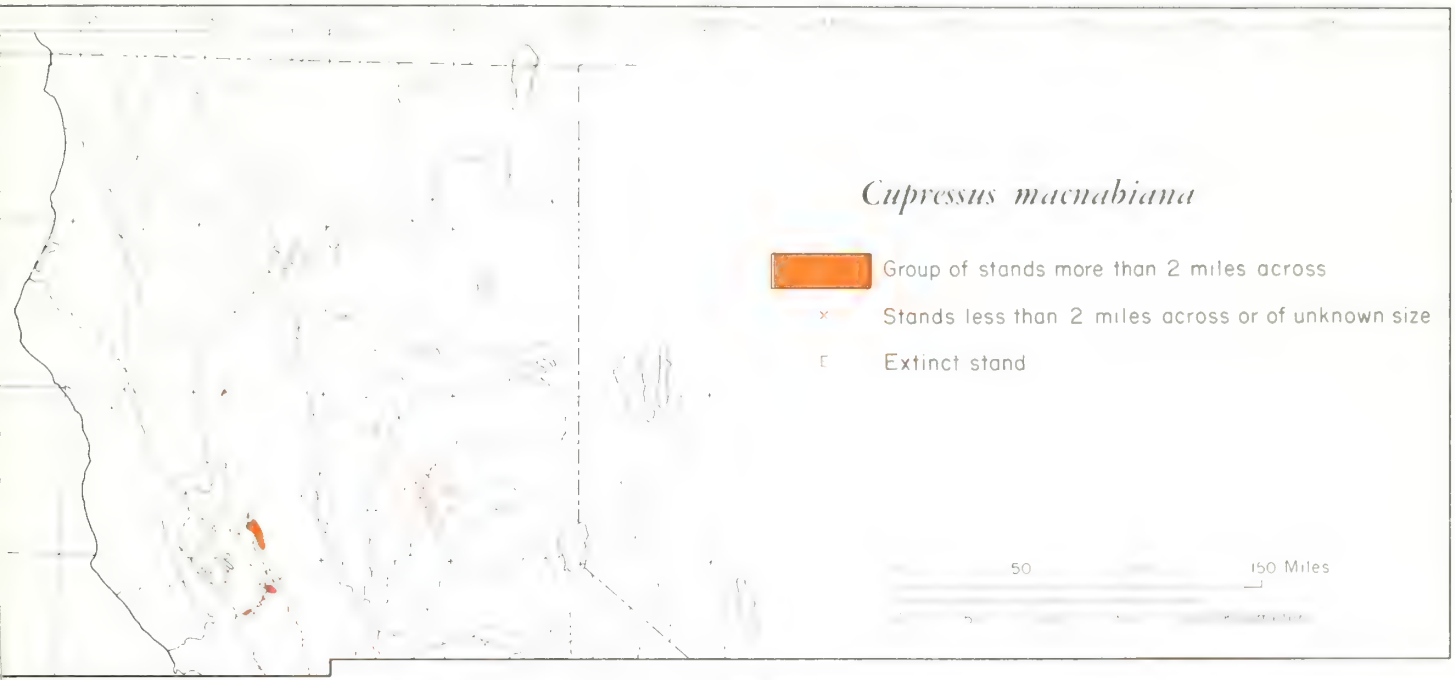



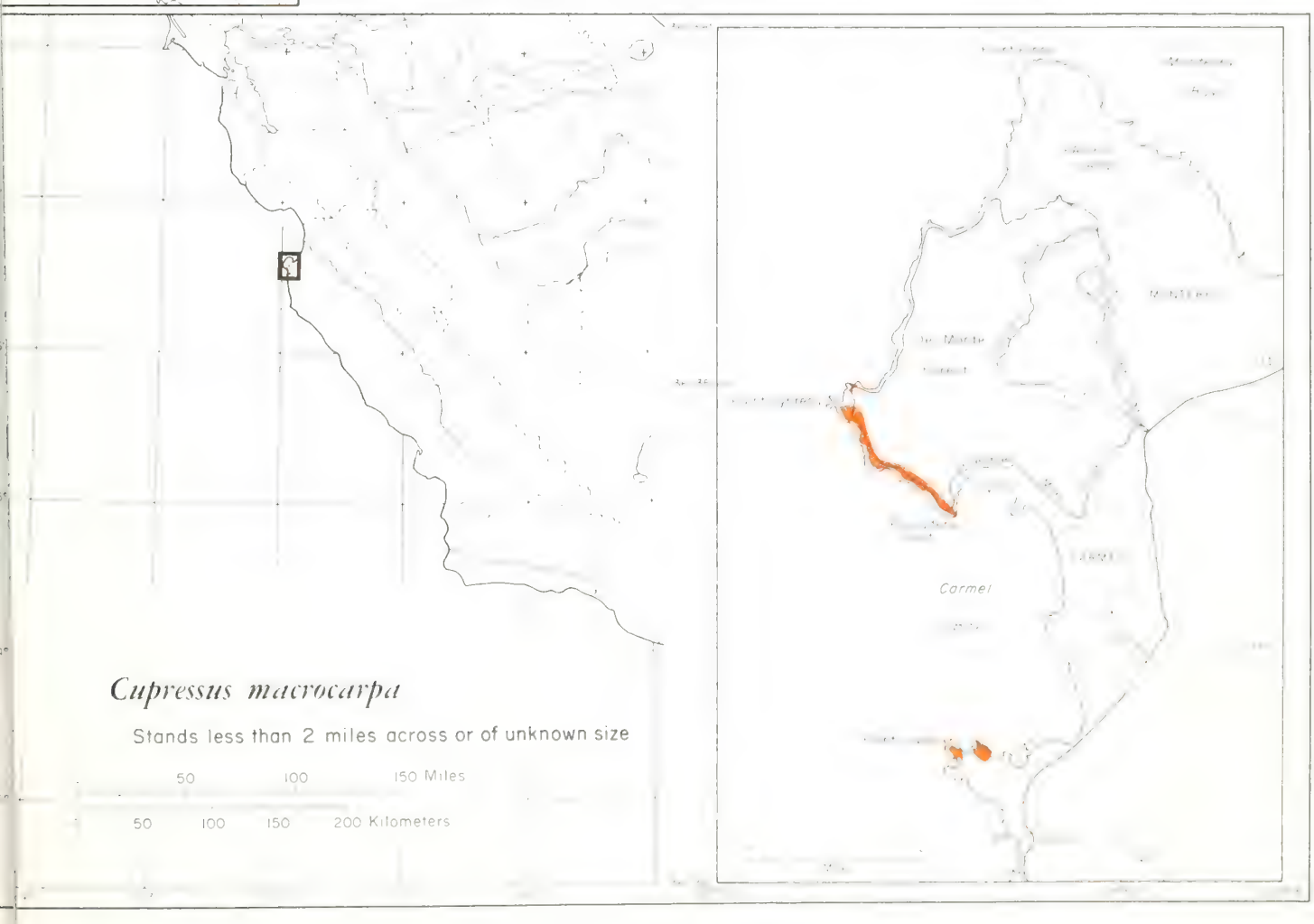

Map 19 (top) Map 20 (bottom)



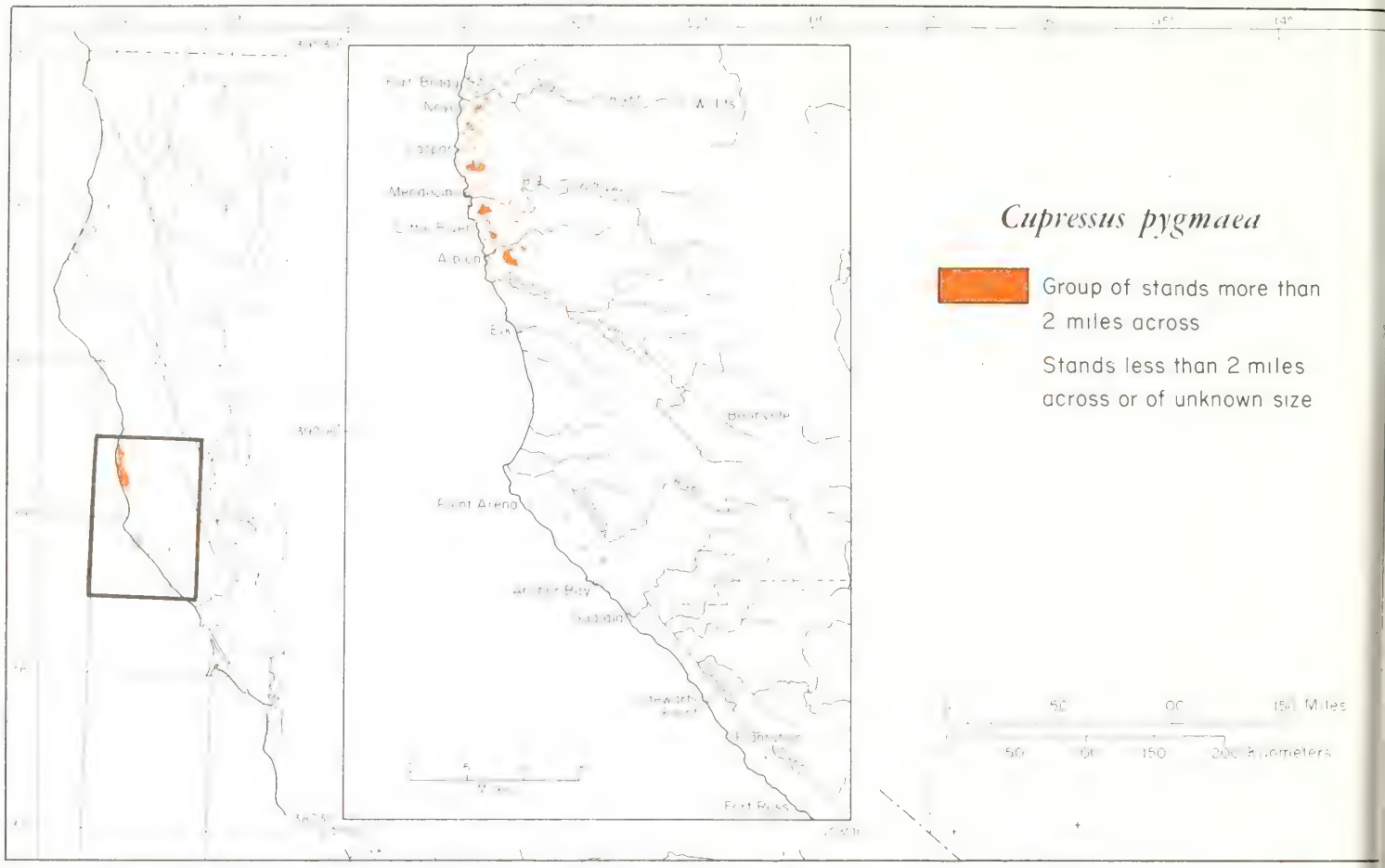



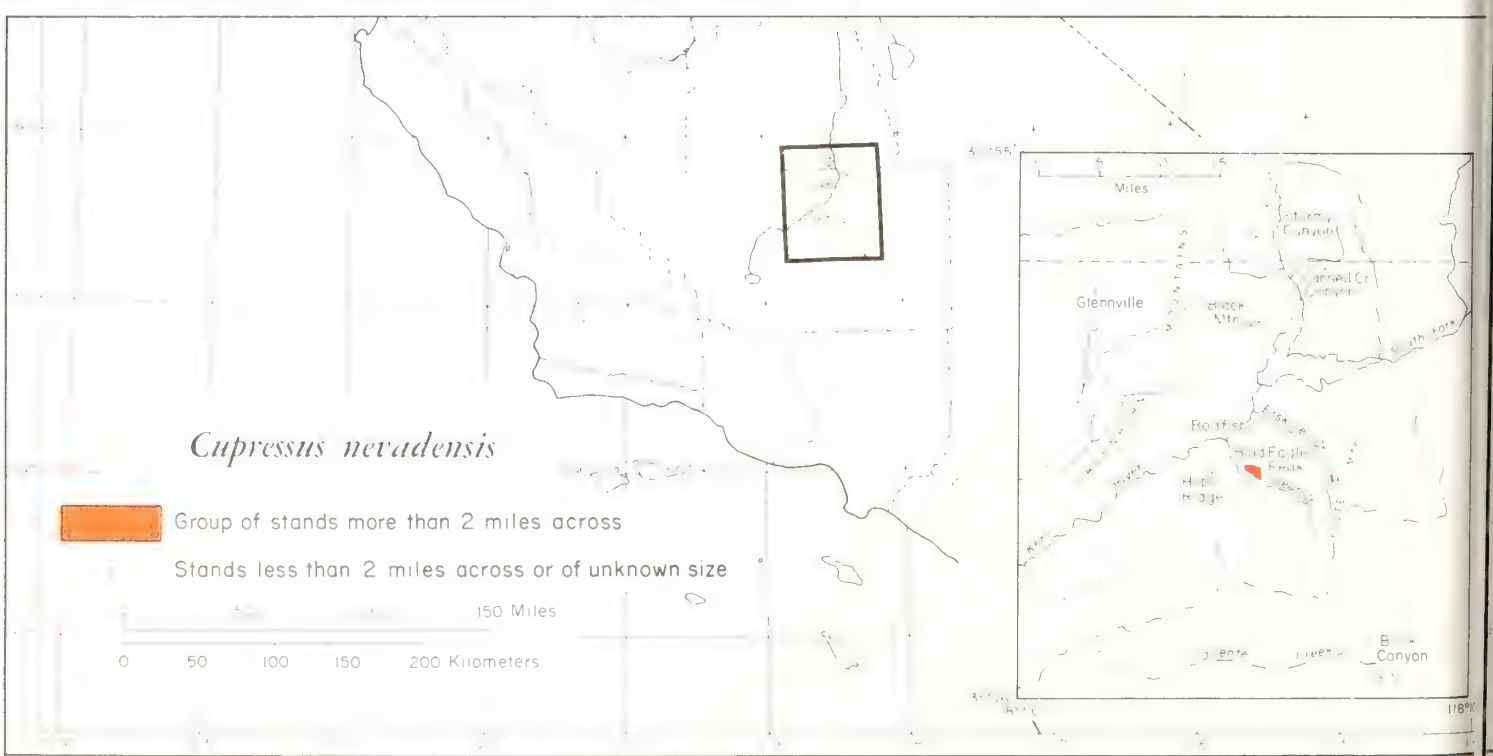

Map 21 (top) Map 22 (bottom)


Cupressus macnabiana
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Extinct stand
50
150 Miles

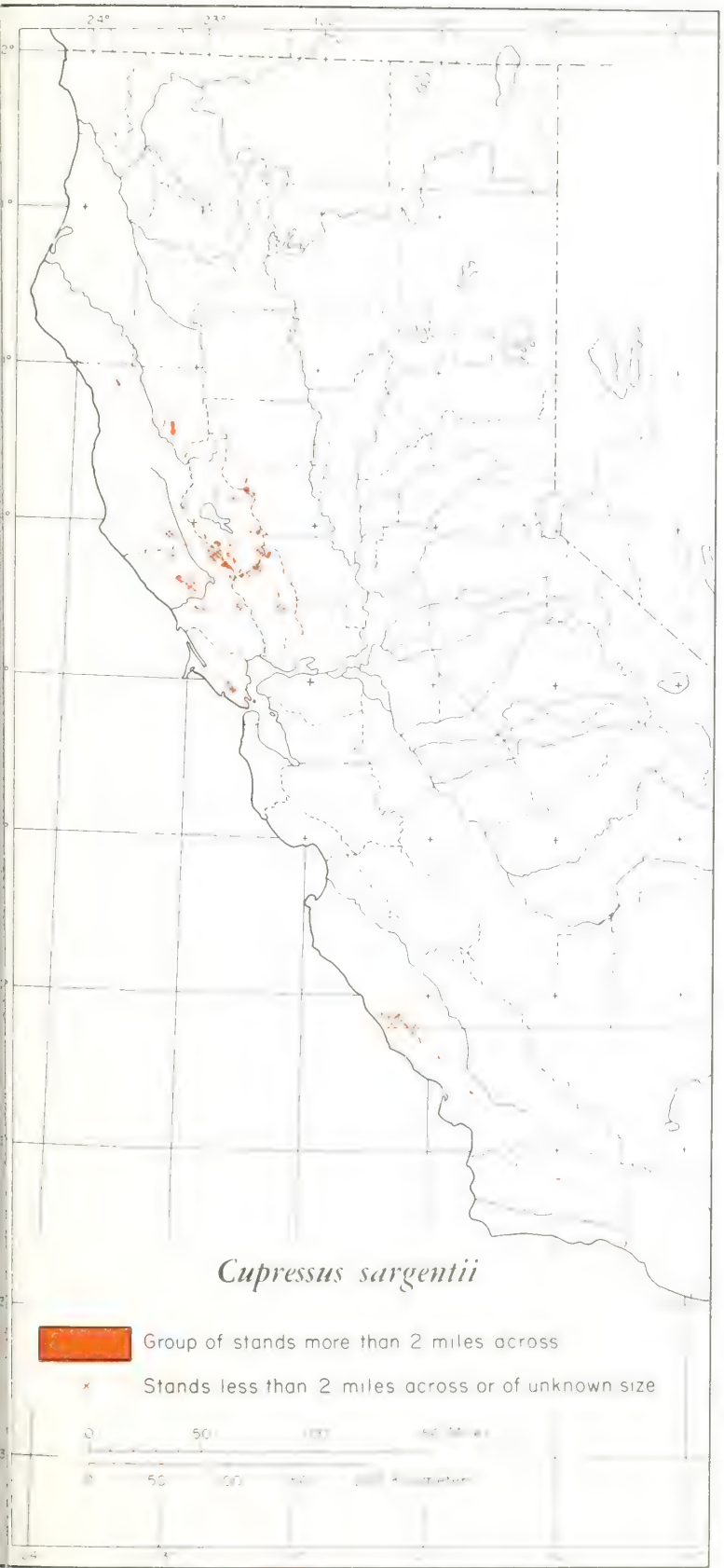



Map 23 (top) Map 24 (bottom)

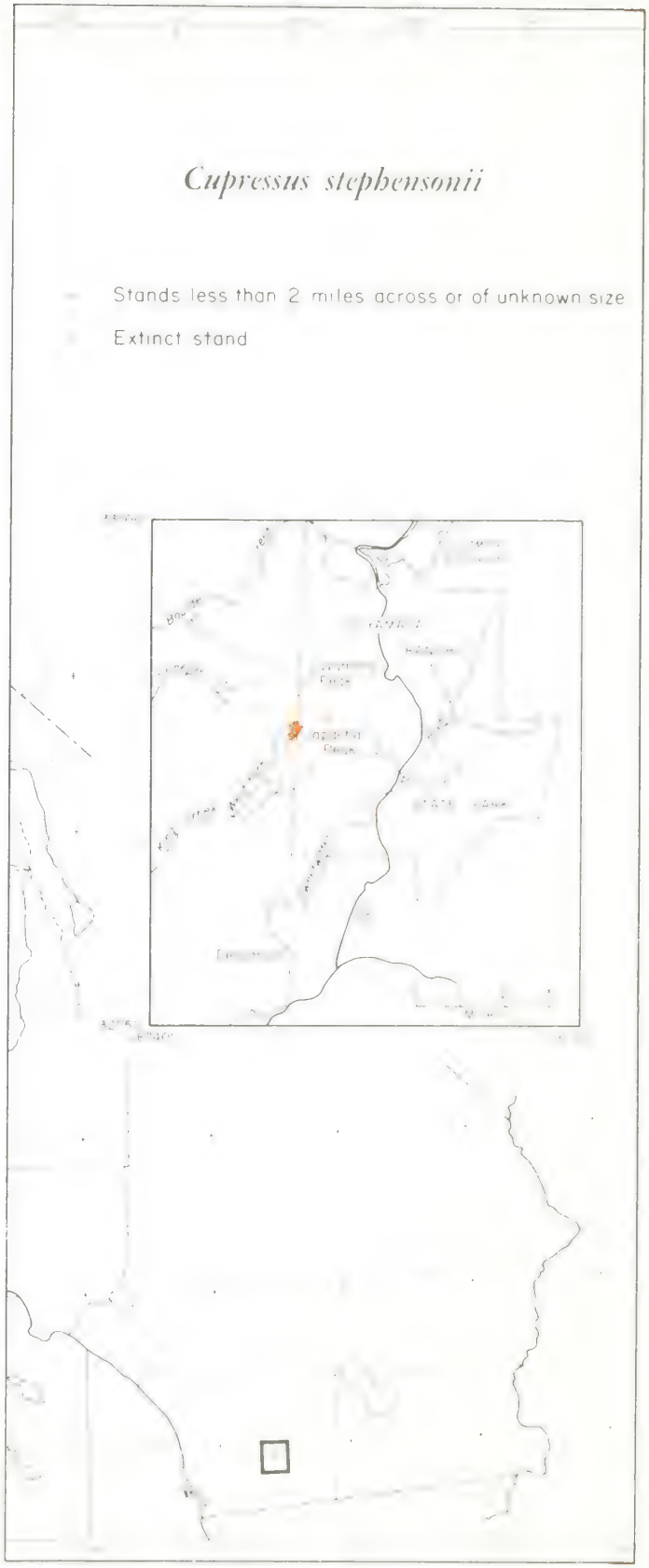


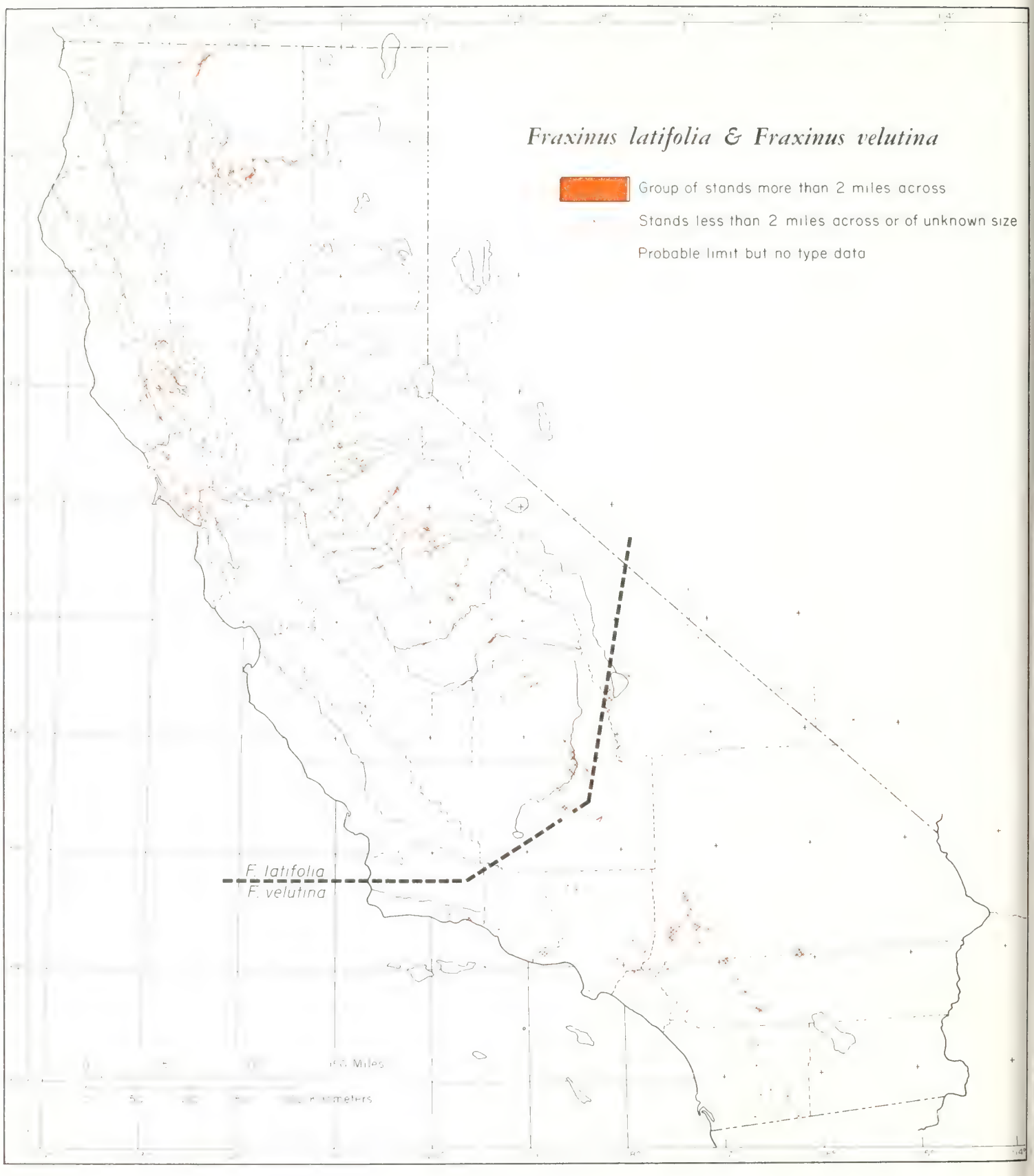

Map 25 (bottom) Map 26 (top)


Cupressus sargentii
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size

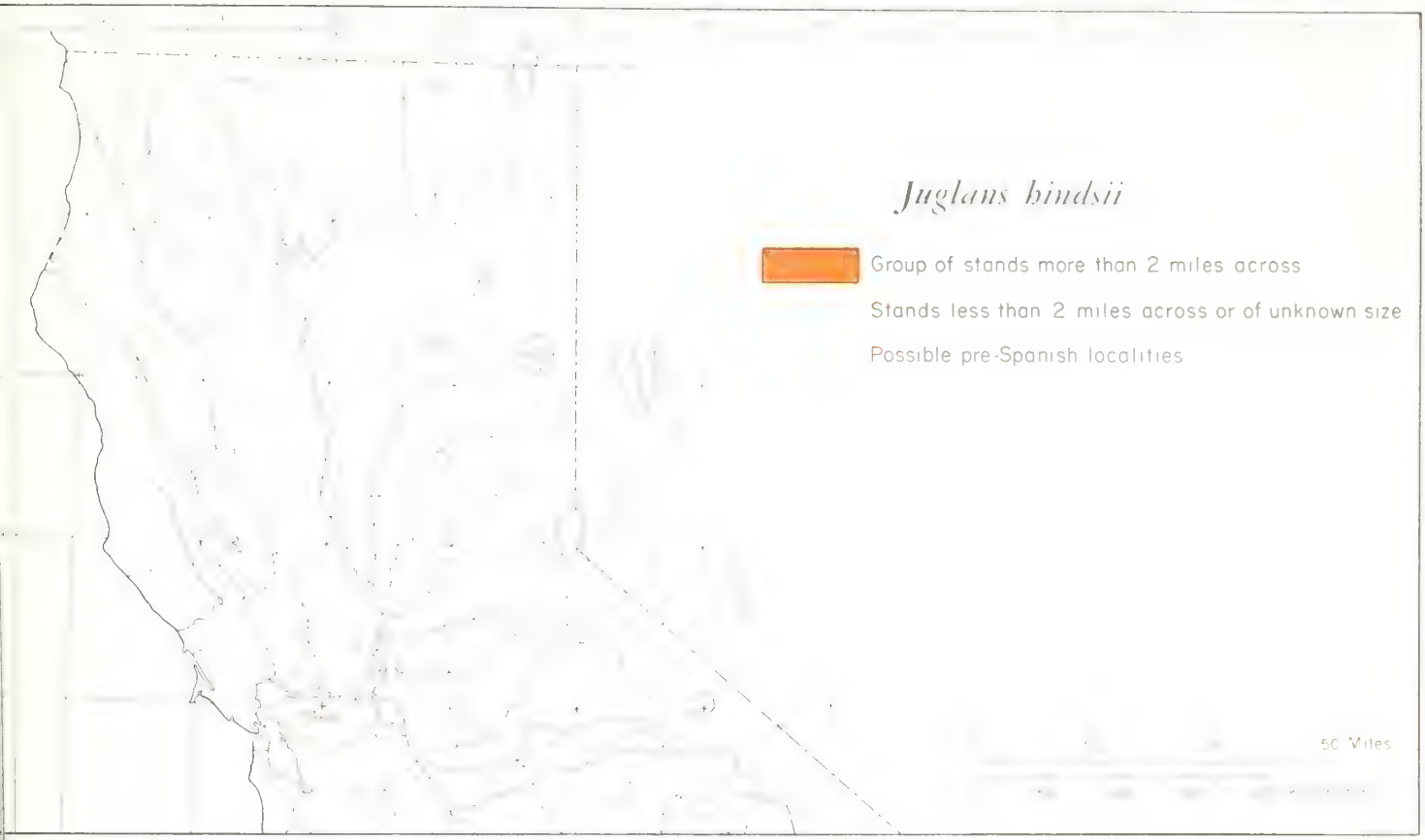
Map 27


Cupressus stephensonii
Stands less than 2 miles across or of unknown size
Extinct stand

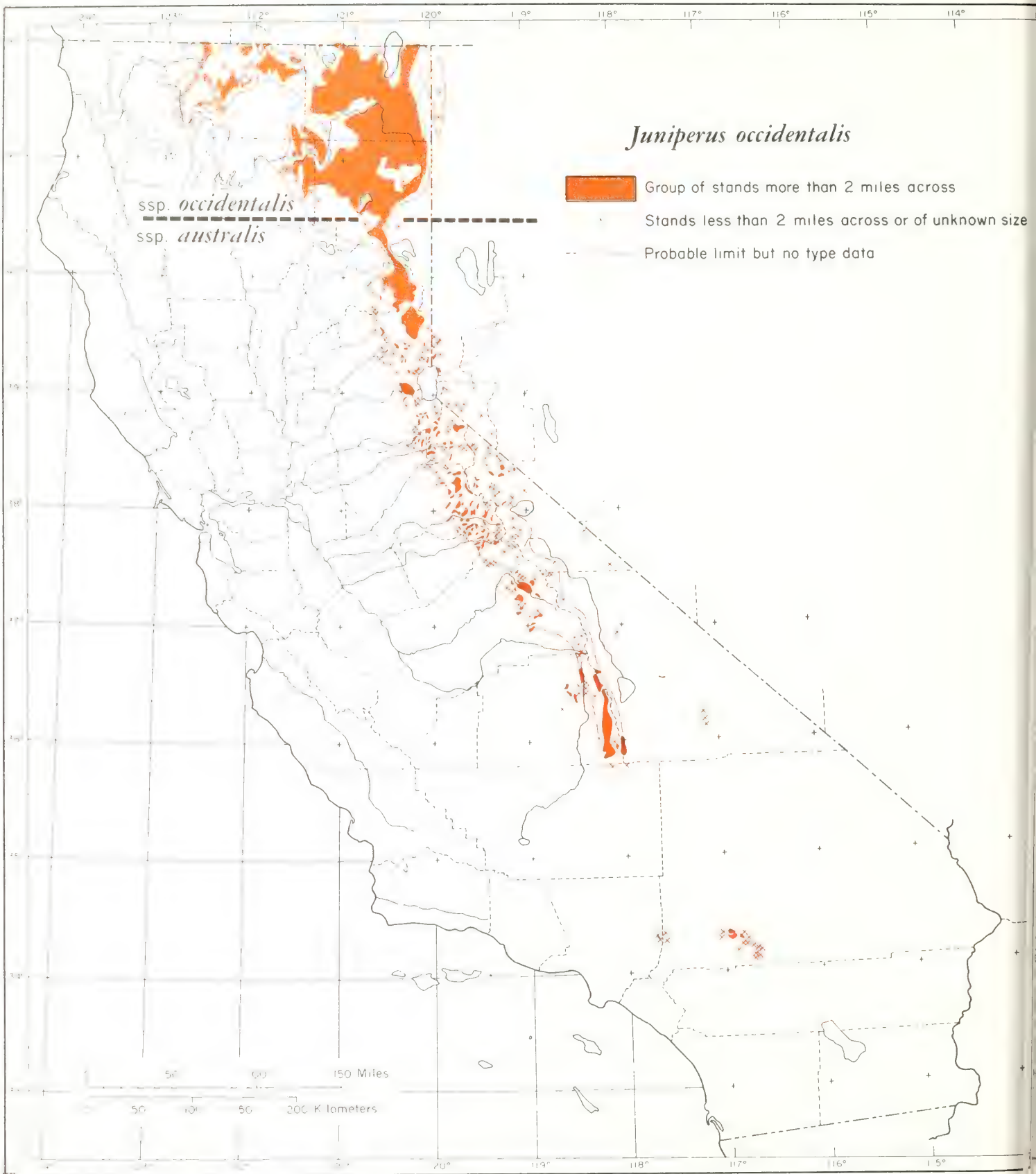
Map 28


Fraxinus latifolia & Fraxinus velutina
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data
F. latifolia
F. velutina

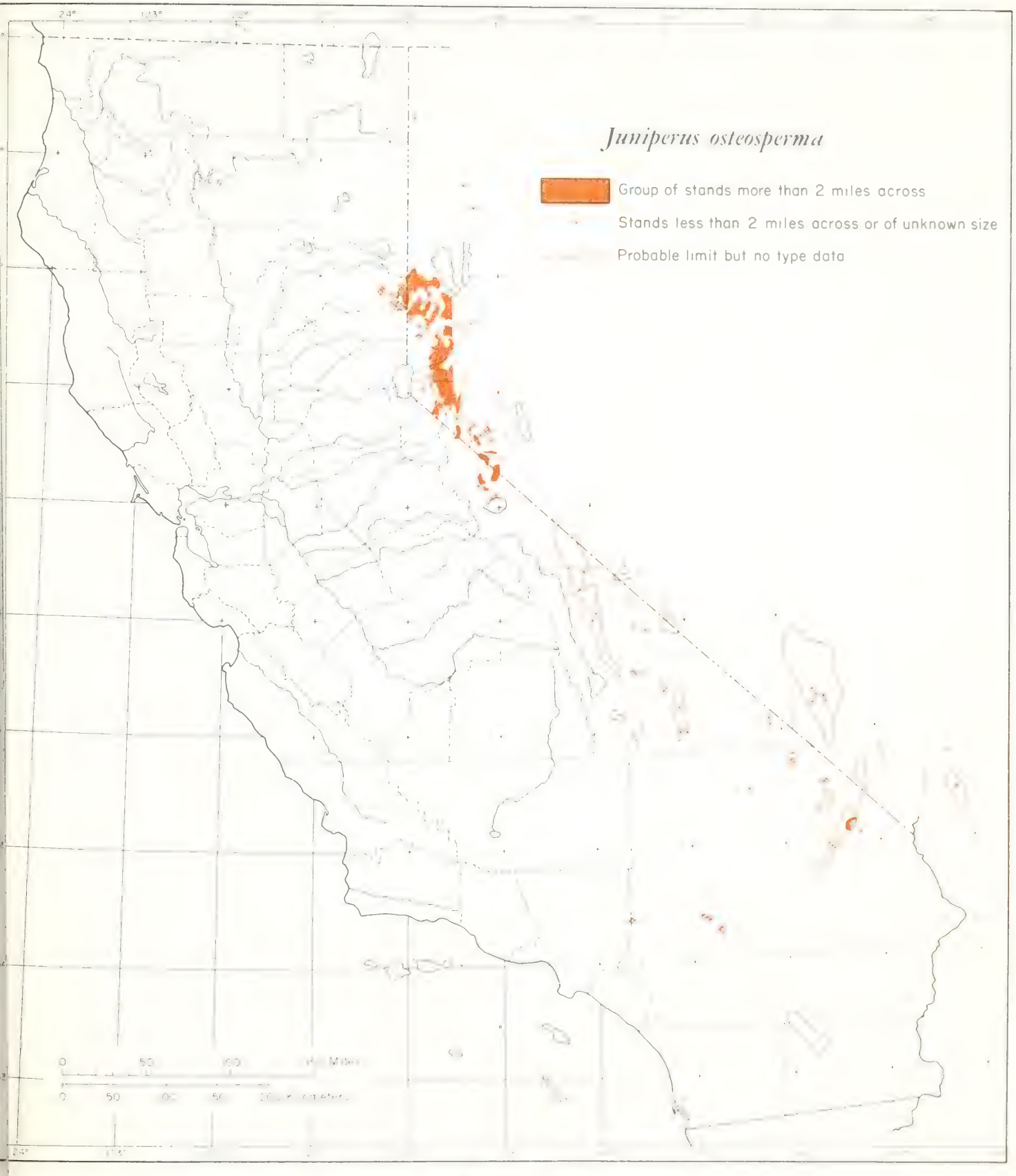
Map 29


Juglans hindsii
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Possible pre-Spanish localities
50 Miles

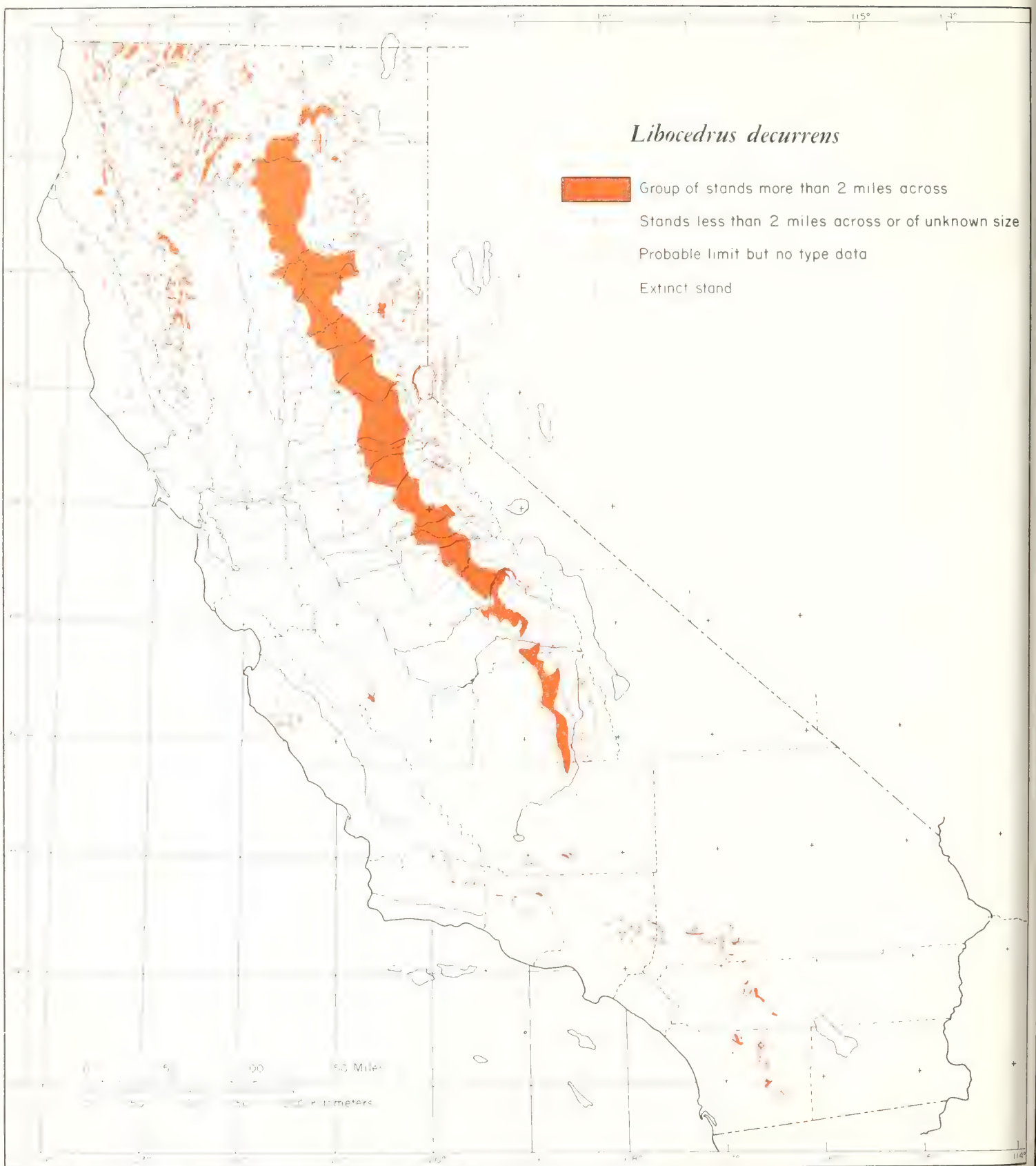
Map 31 (top)  Map 30 (bottom)


Juniperus occidentalis
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data
ssp. occidentalis
ssp. australis
50
100
150 Miles
50
100
50
200 Kilometers

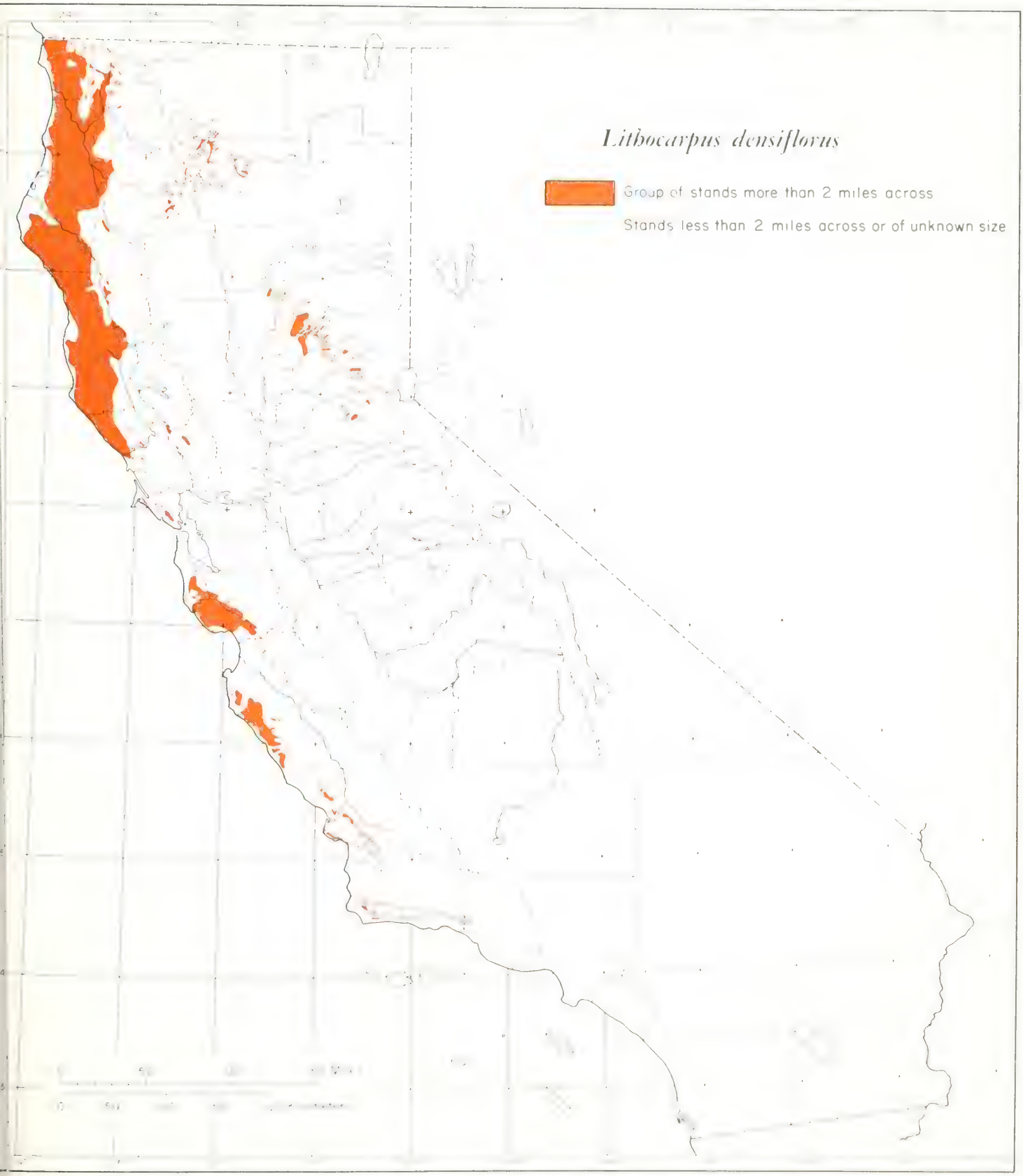
Map 32


Juniperus osteosperma
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data

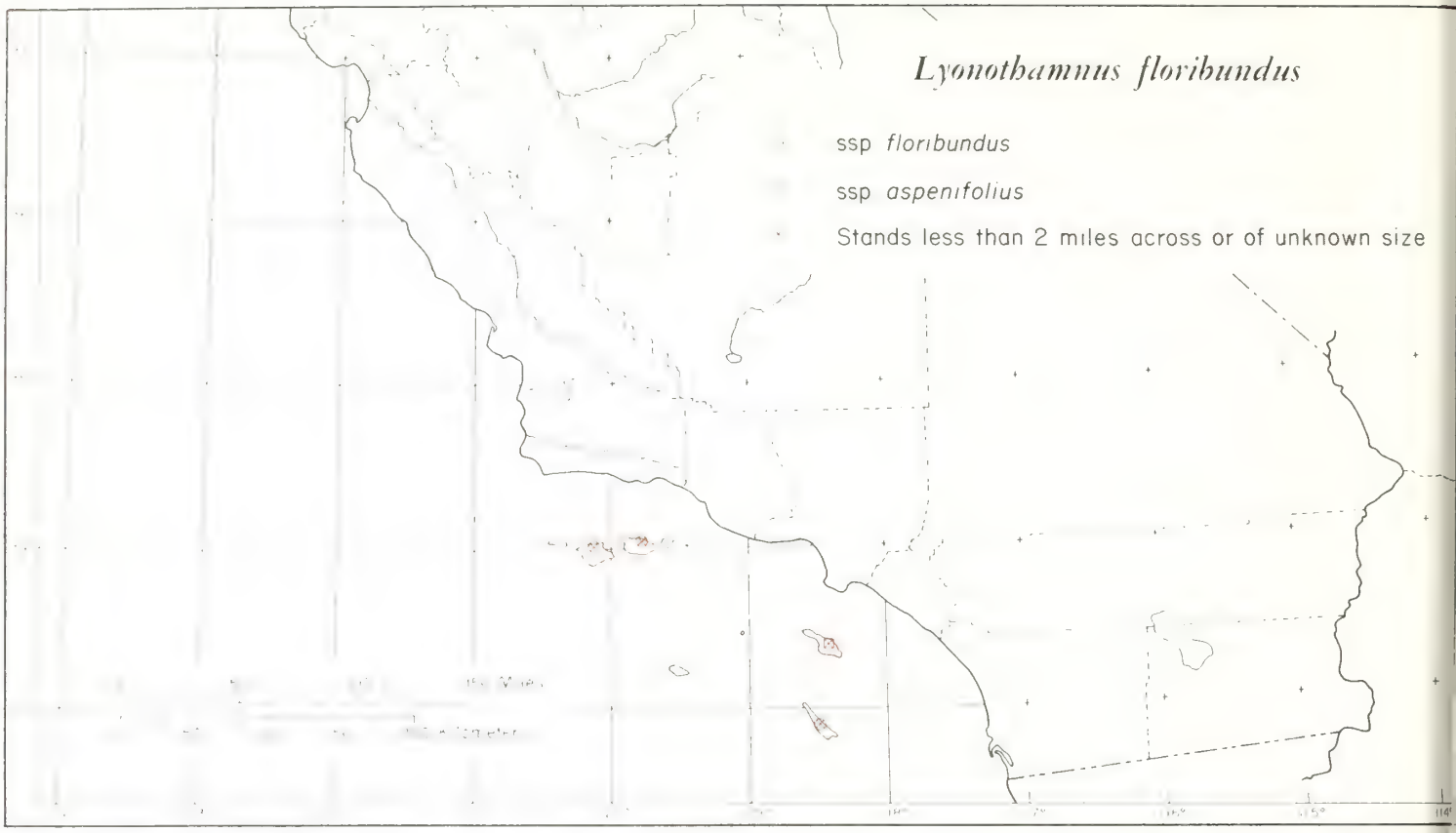
Map 33

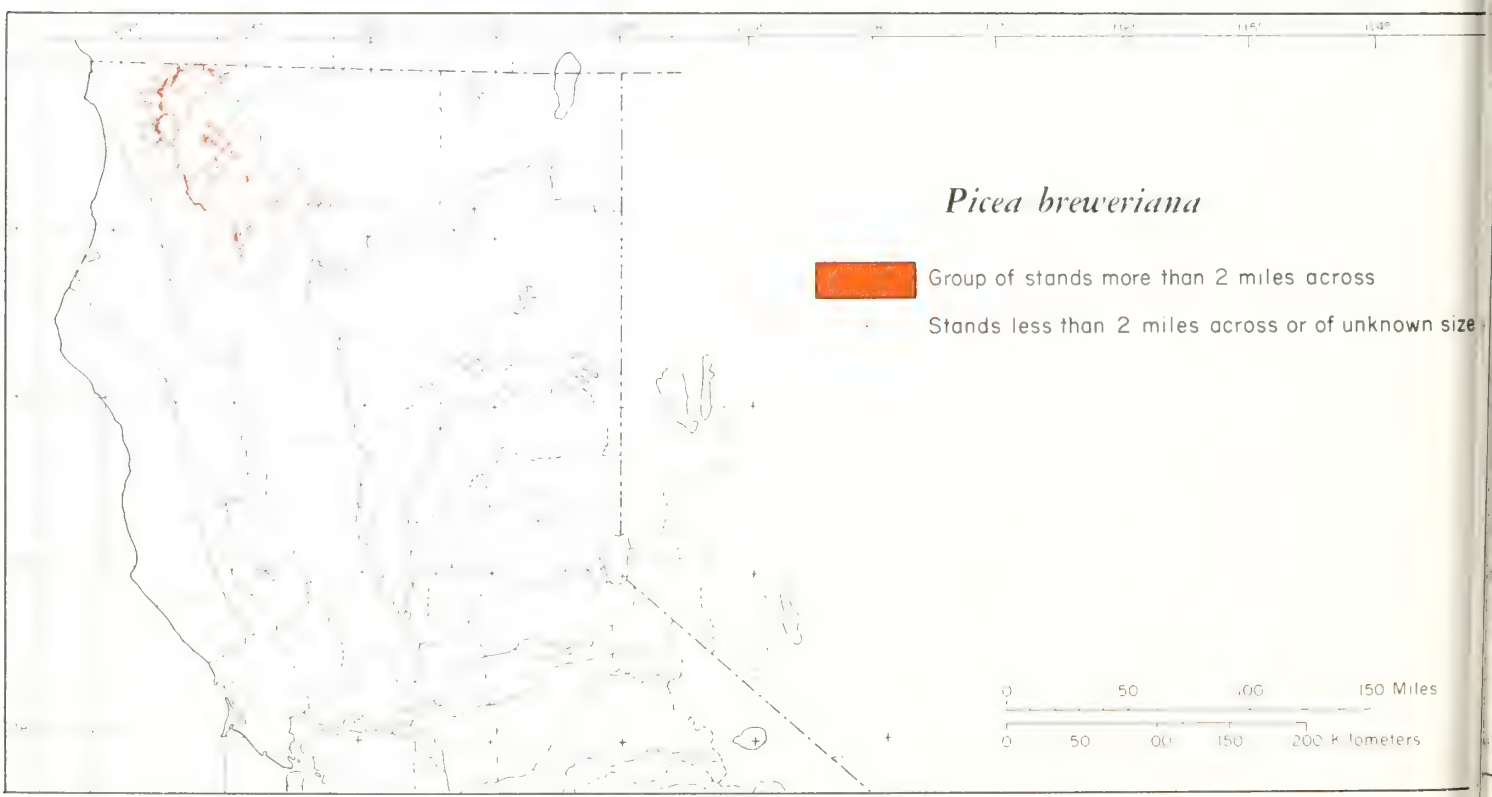

Libocedrus decurrens
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data
Extinct stand
115°
50 Miles

Map 34

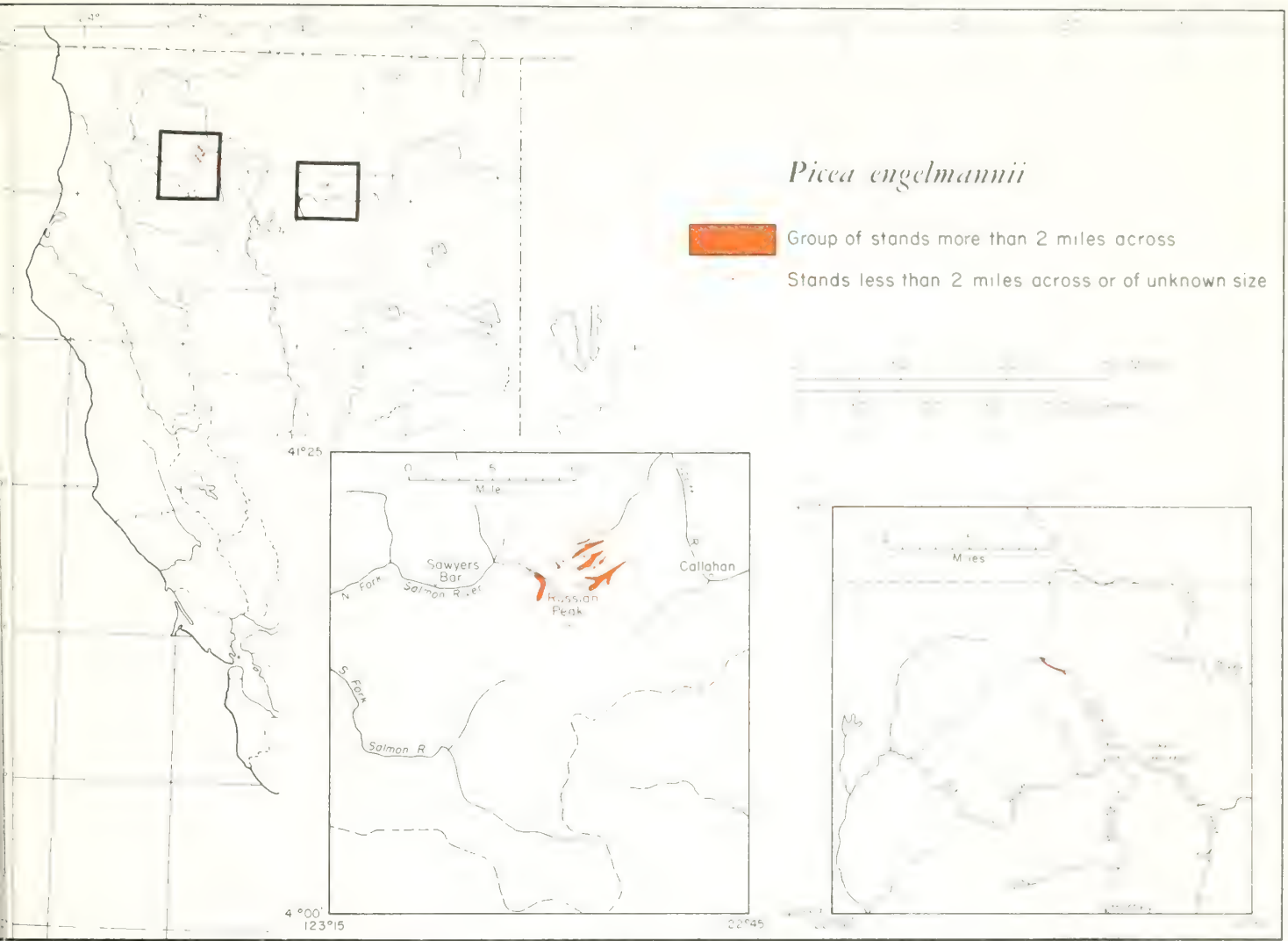

*Lithocarpus densiflorus*
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size

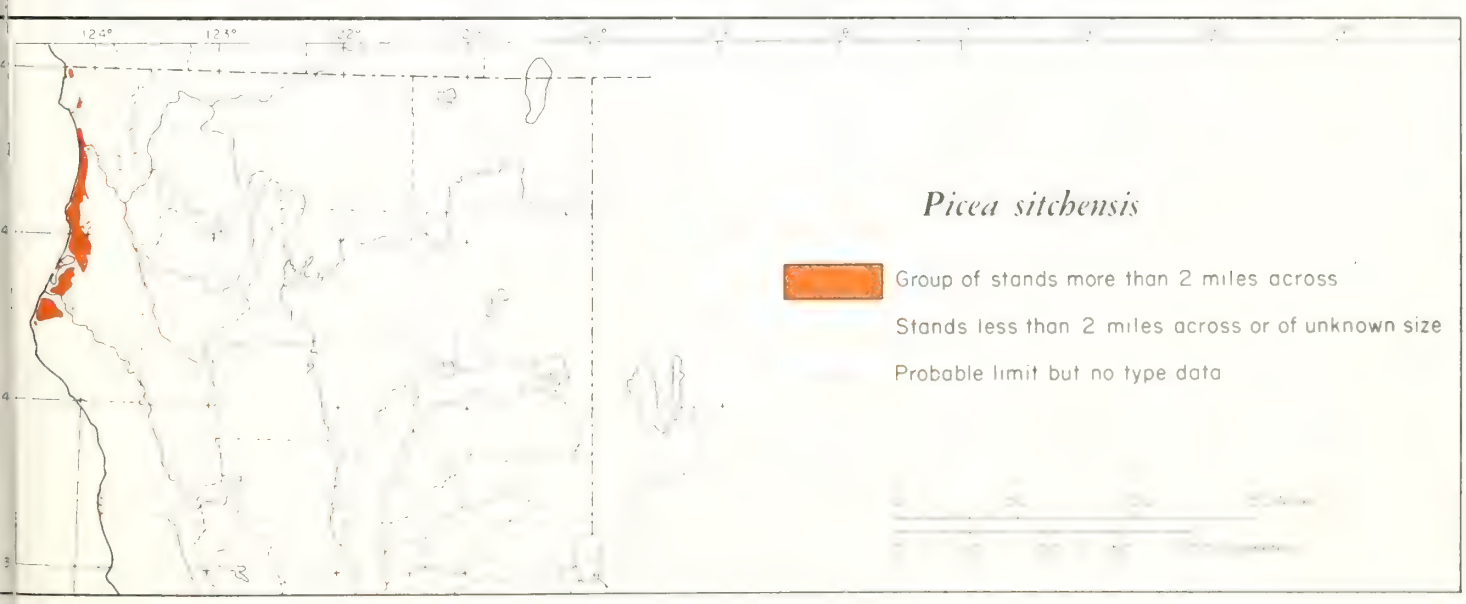
Map 35



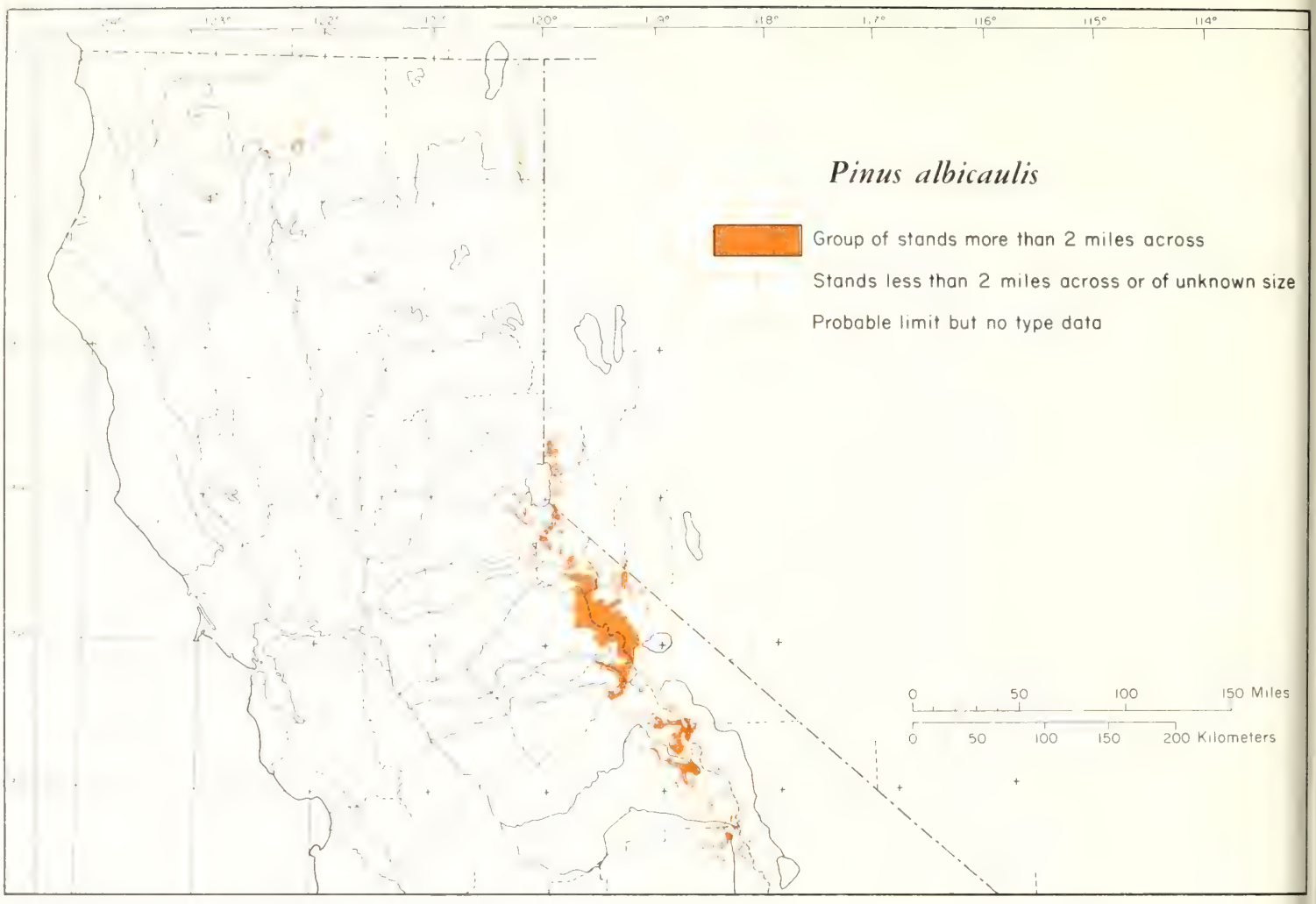


Picea breweriana
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
0 50 100 150 Miles
0 50 100 150 200 Kilometers

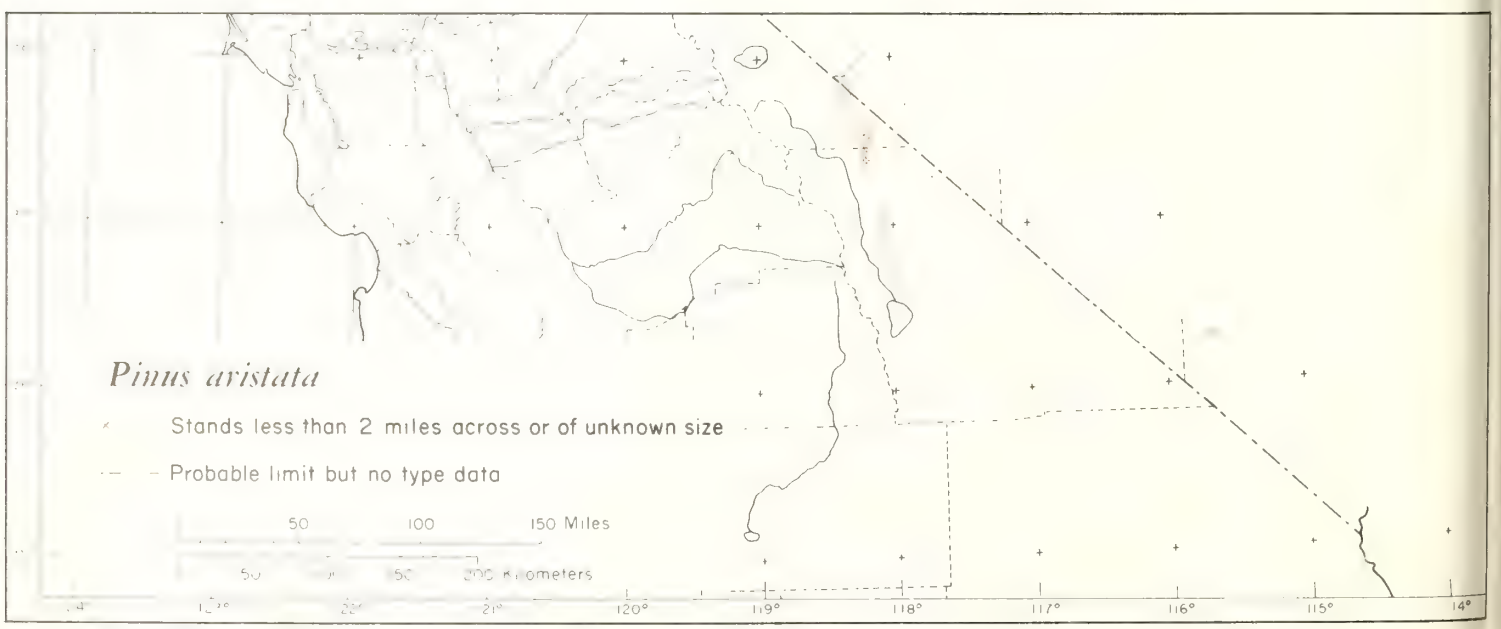
Map 36 (top) Map 37 (bottom)



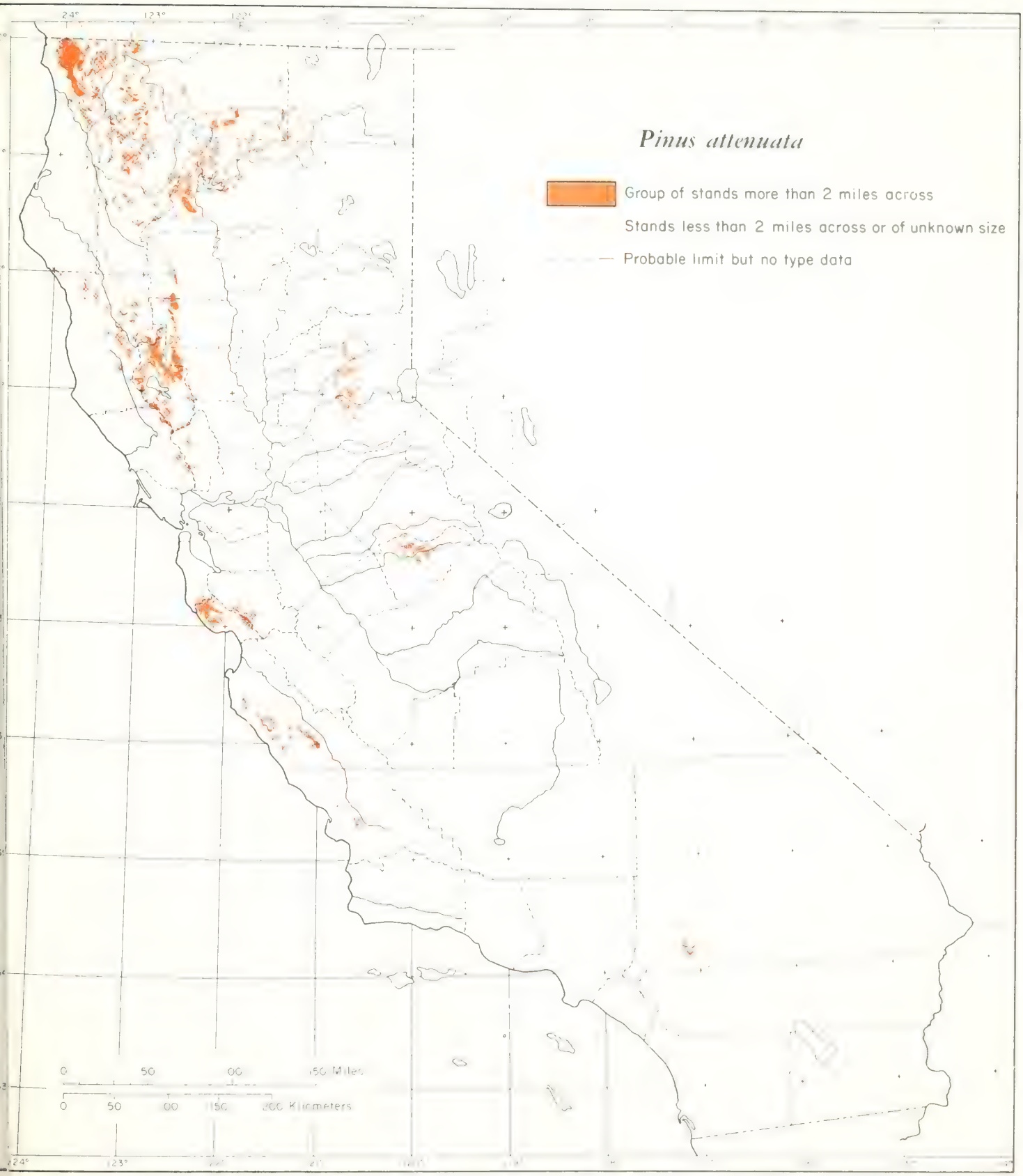


124°
123°
42°
Picea sitchensis
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data

Map 38 (top)  Map 39 (bottom)

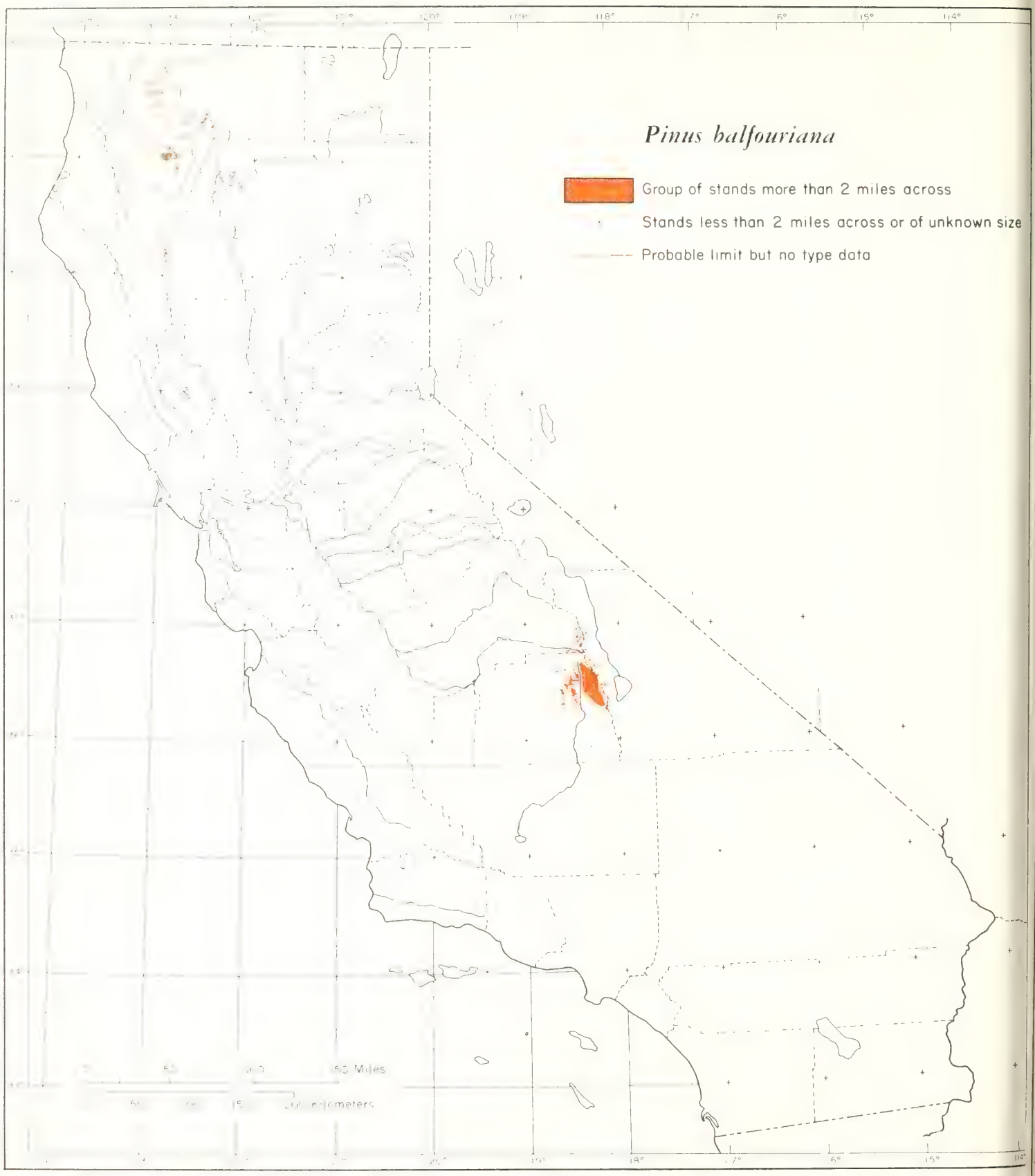

Pinus albicaulis
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data
0 50 100 150 Miles
0 50 100 150 200 Kilometers


Pinus aristata
Stands less than 2 miles across or of unknown size
Probable limit but no type data
50 100 150 Miles
50 100 200 Kilometers

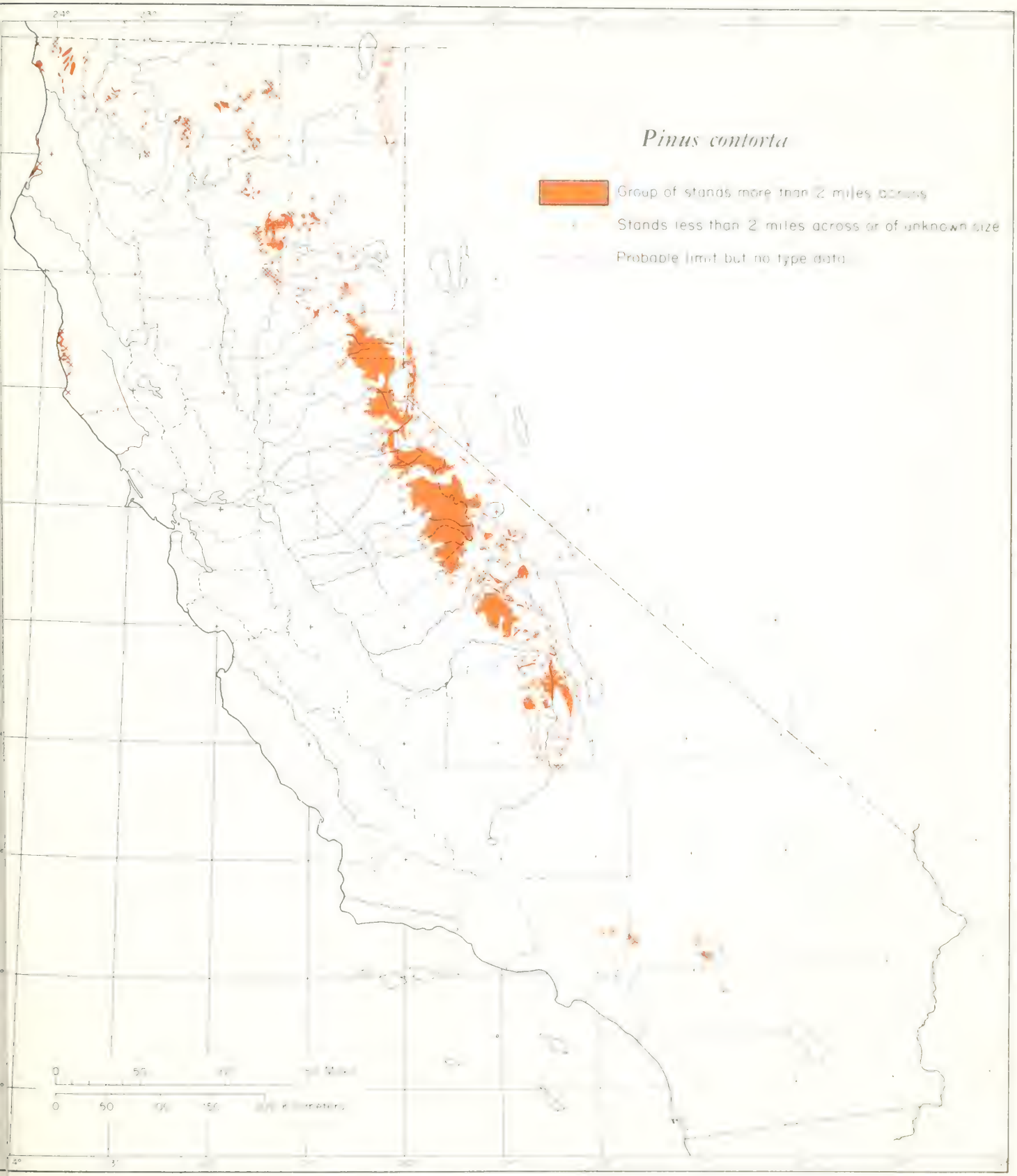
Map 40 (top) Map 41 (bottom)


Pinus attenuata
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data
0 50 100 150 Miles
0 50 100 150 200 Kilometers

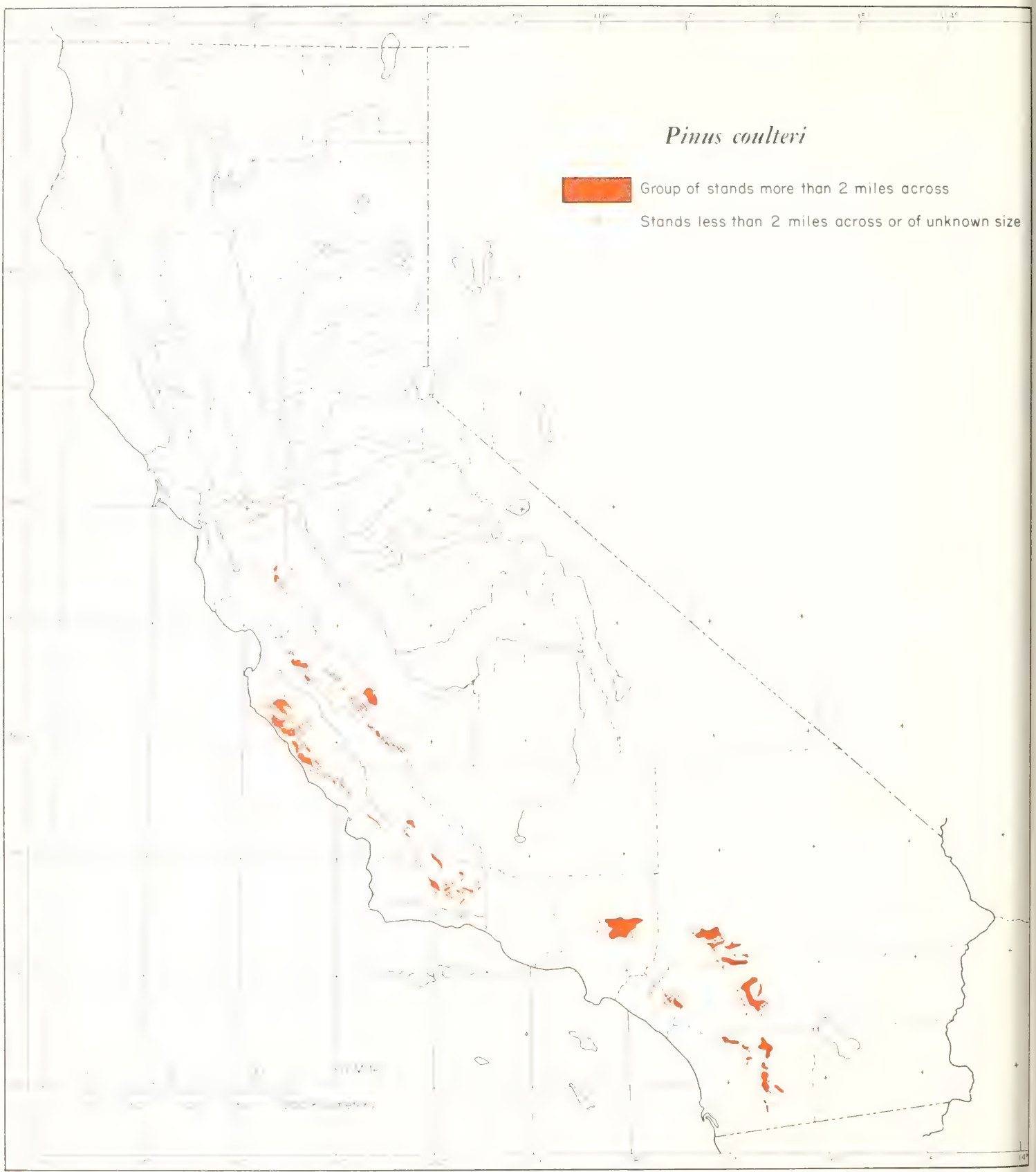
Map 42


Pinus balfouriana
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data
50 Miles

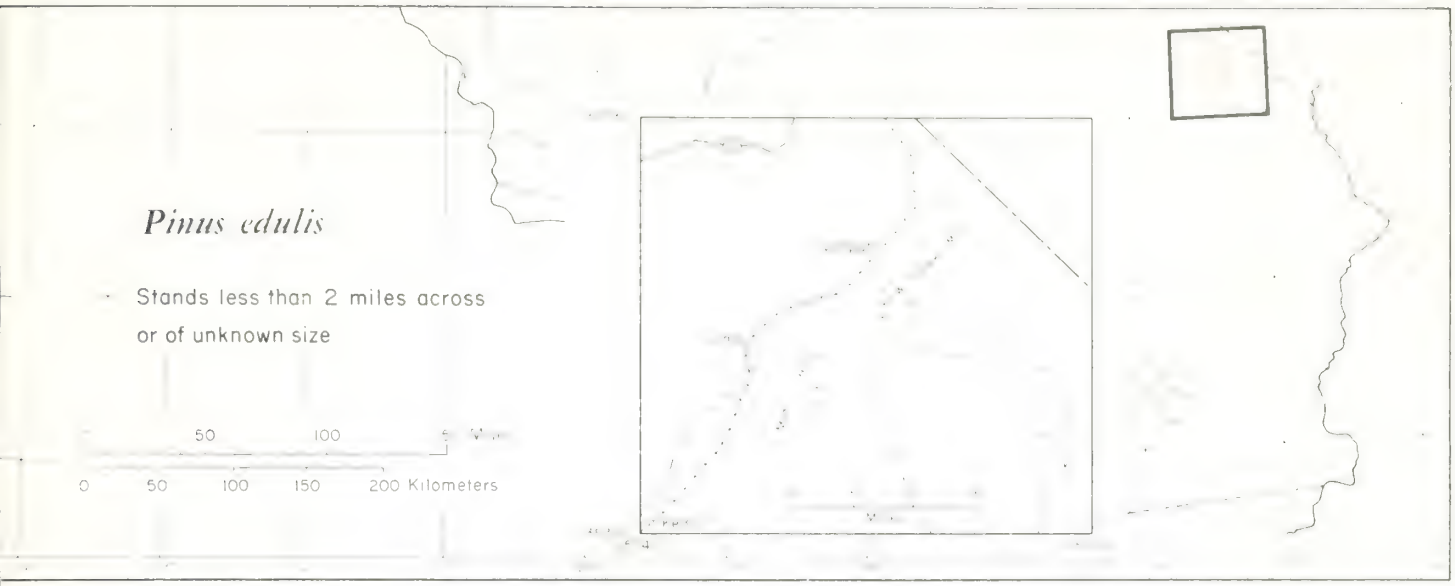
Map 43

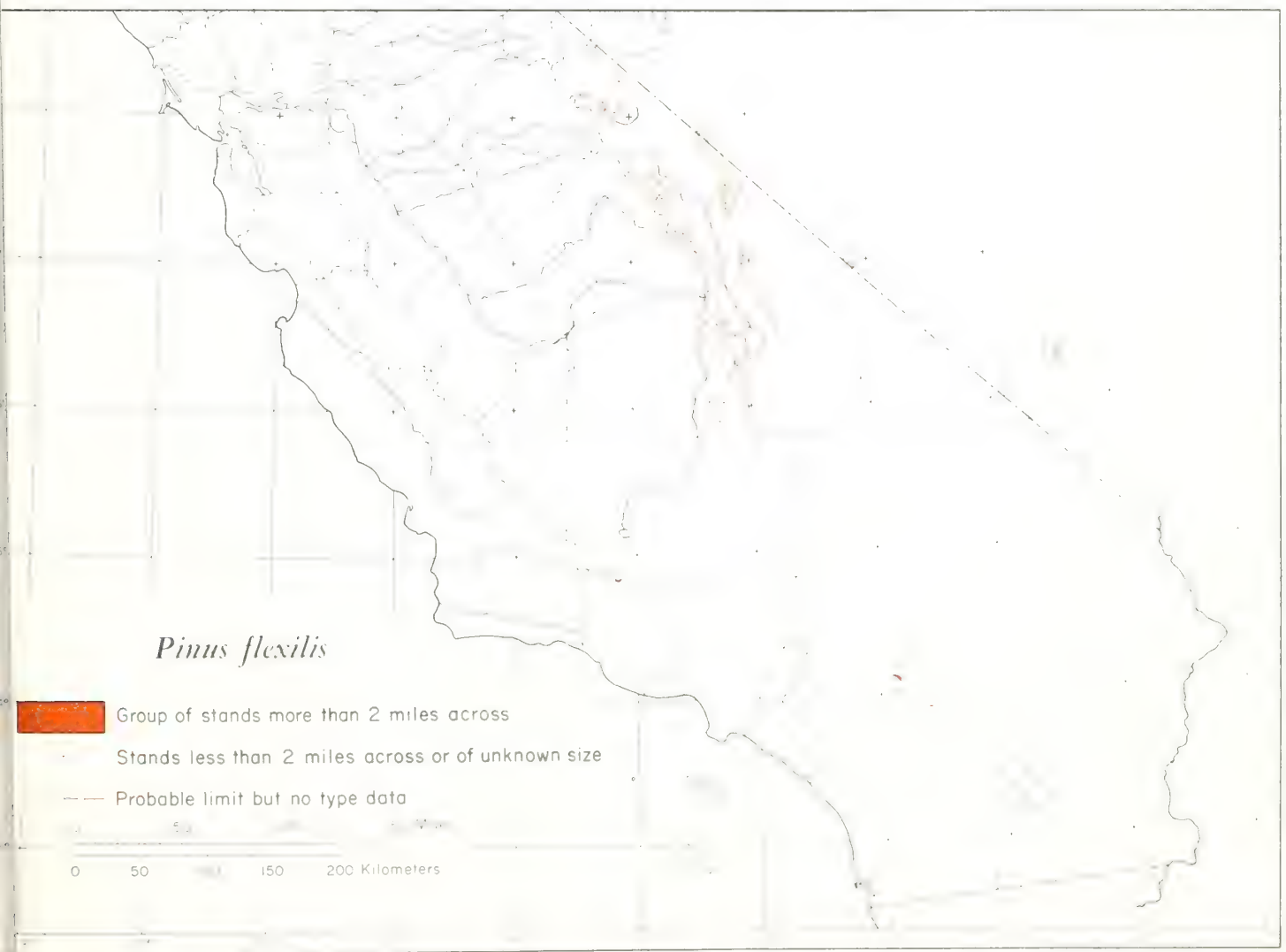

Pinus contorta
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data

Map 44

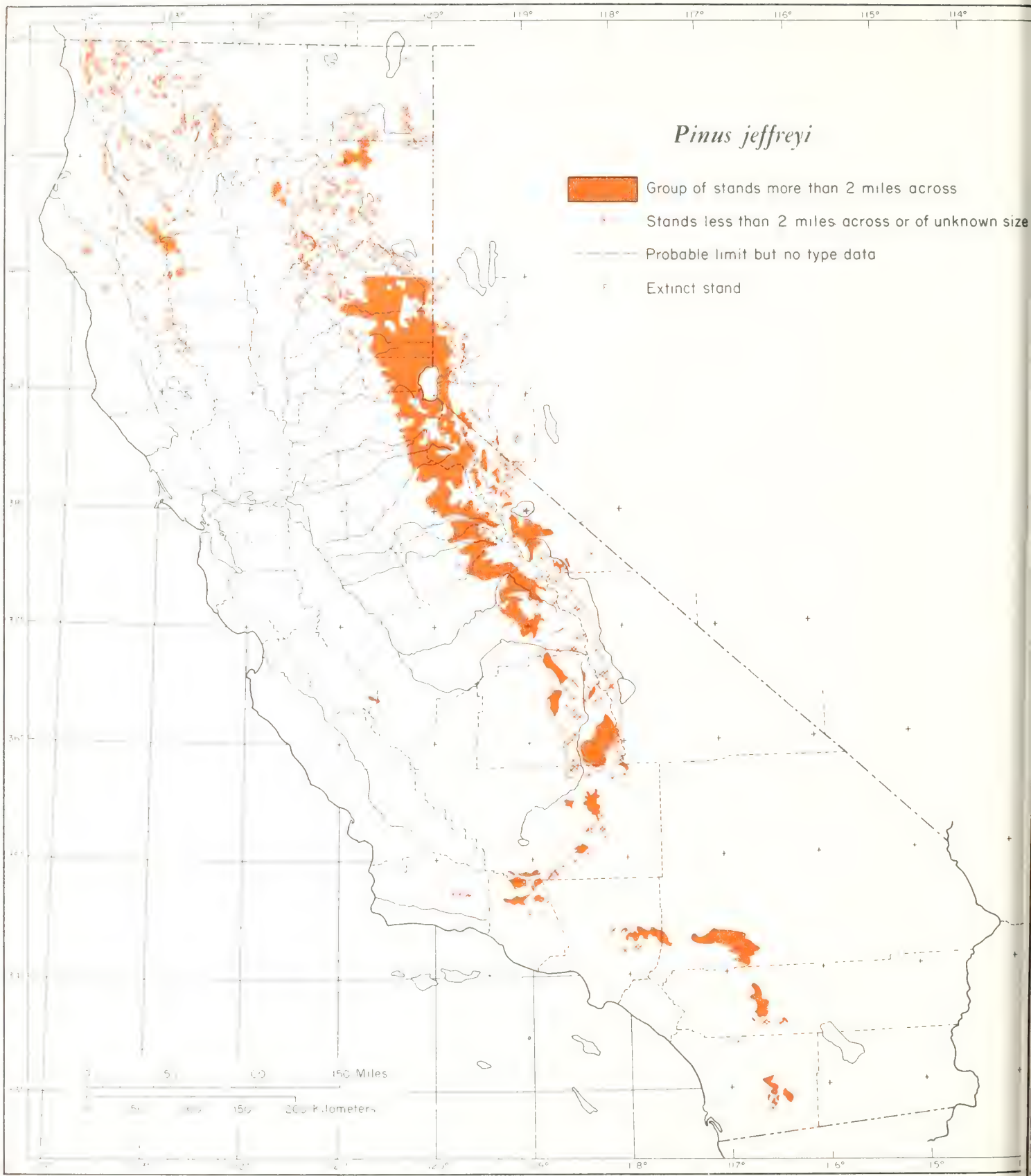

Pinus coulteri
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size

Map 45

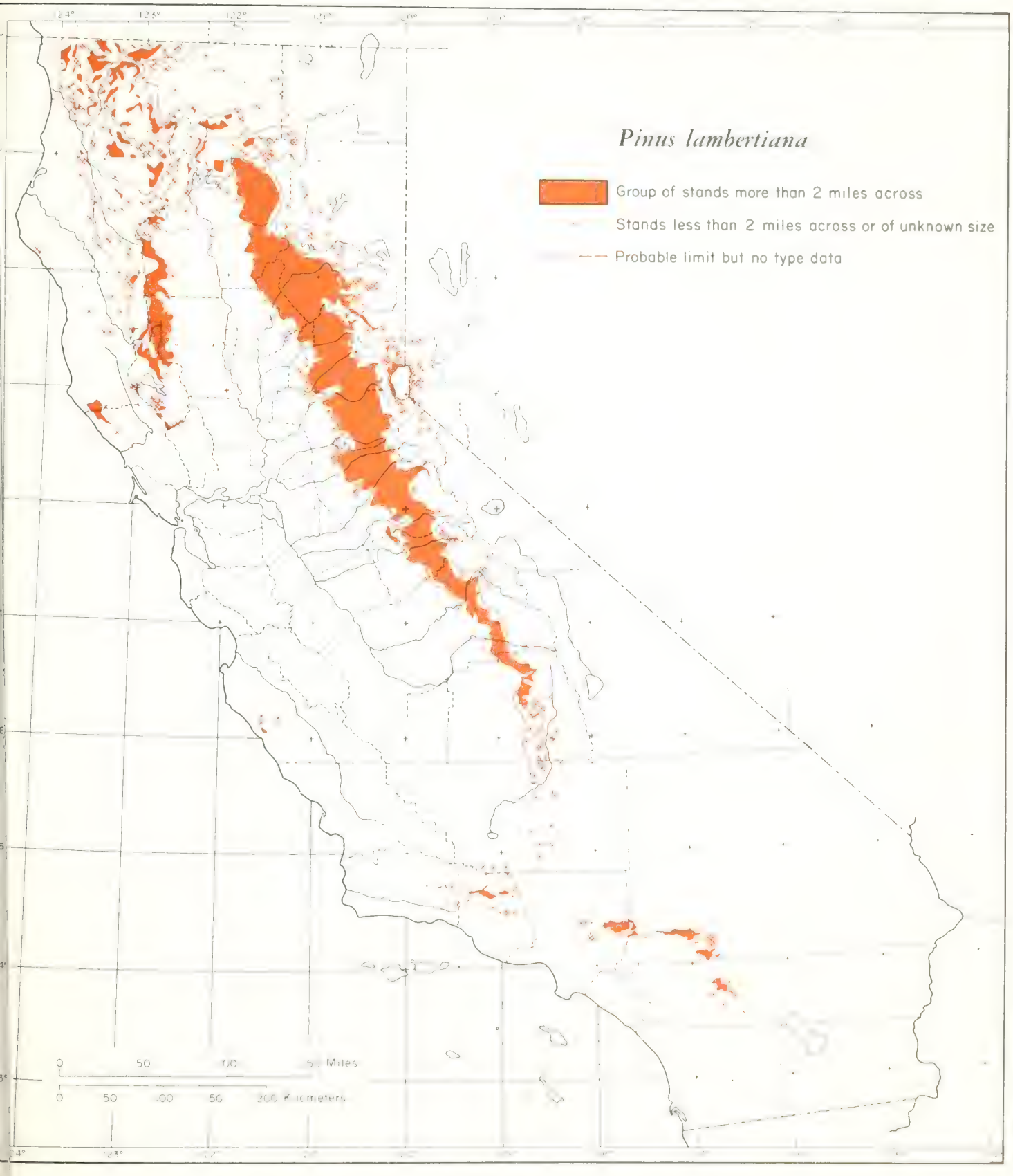


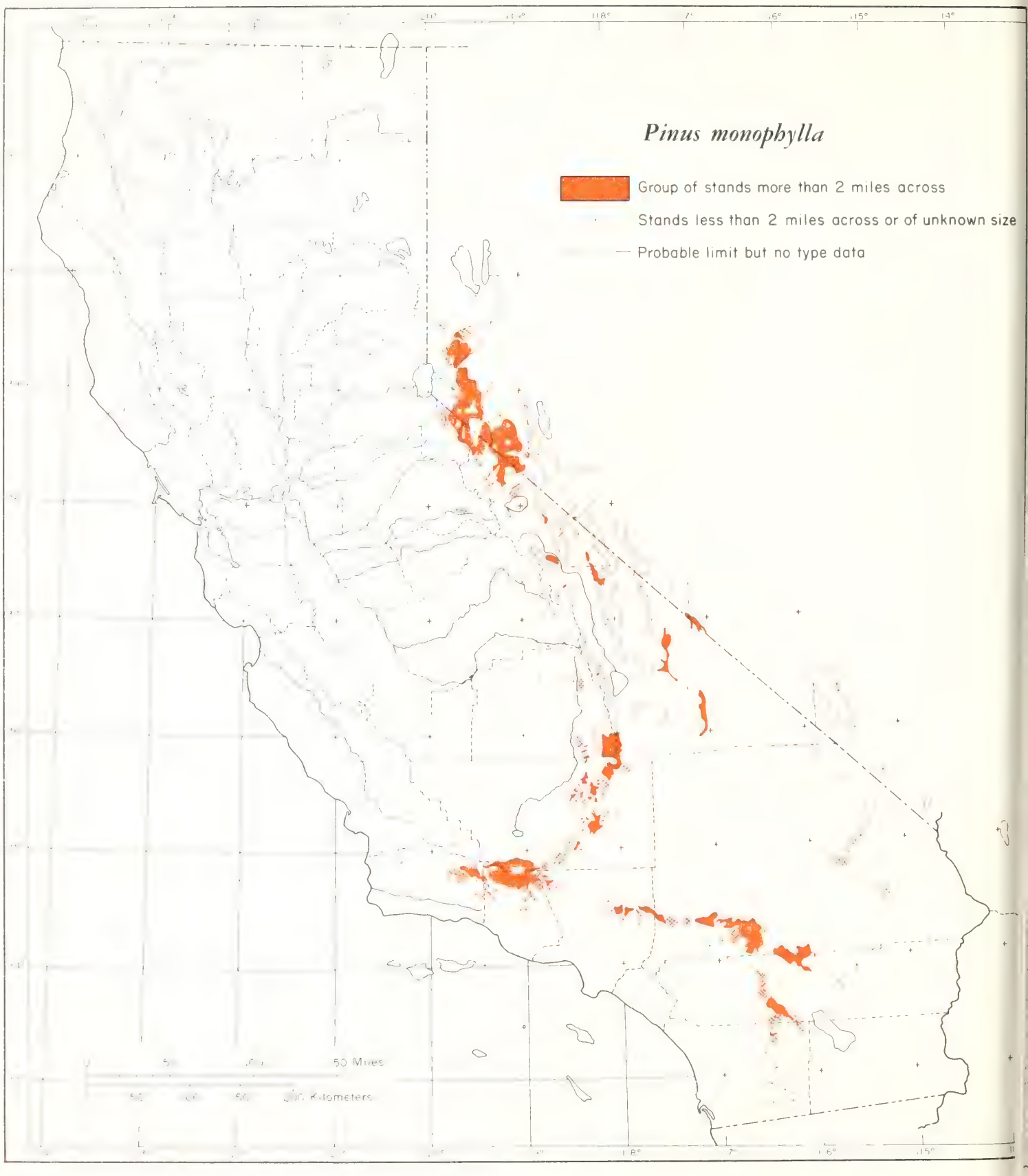

Map 46 (top) Map 47 (bottom)


Pinus jeffreyi
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data
Extinct stand
Miles
Kilometers

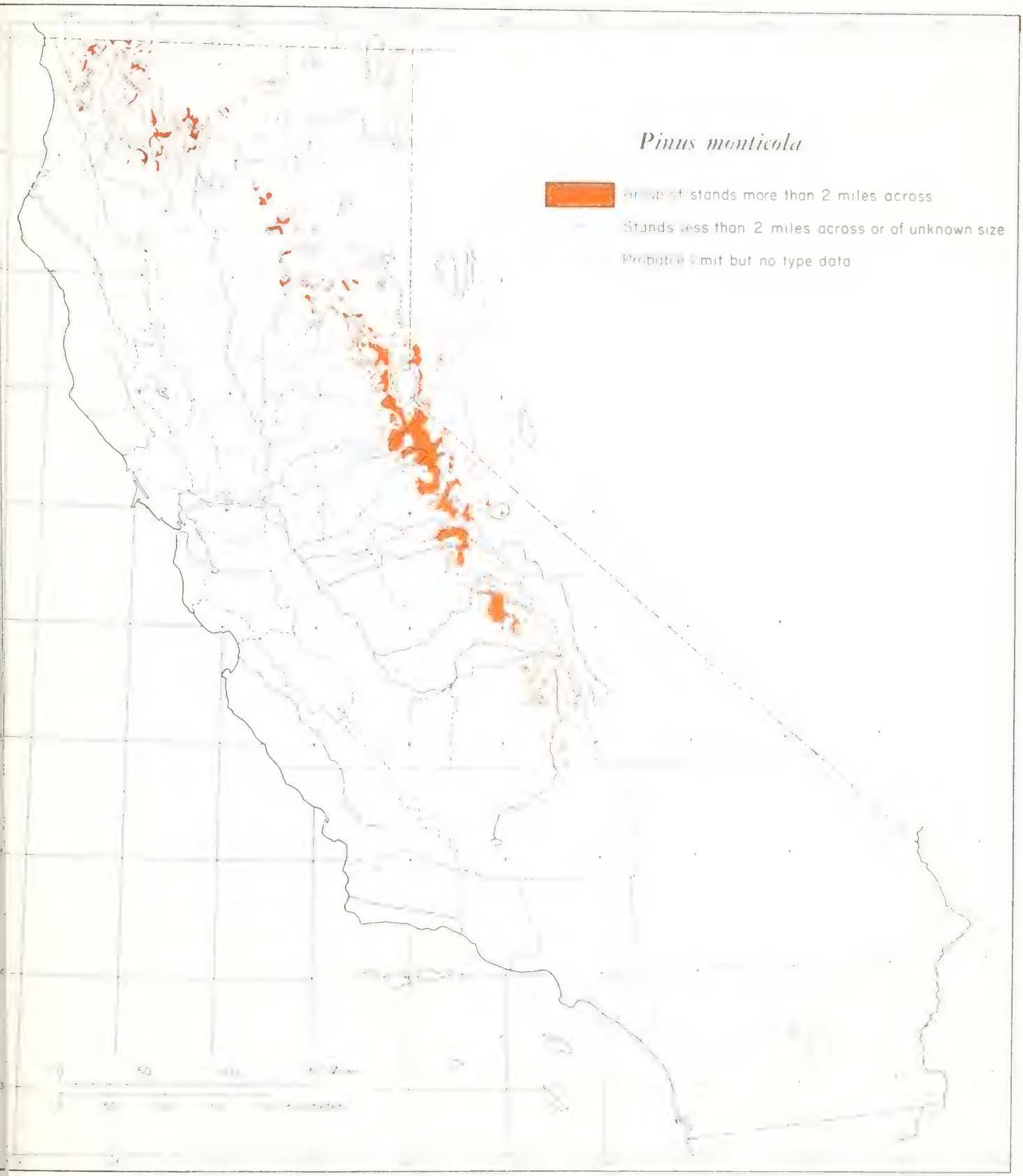
Map 48


Pinus lambertiana
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data
0 50 100 Miles
0 50 100 200 Kilometers

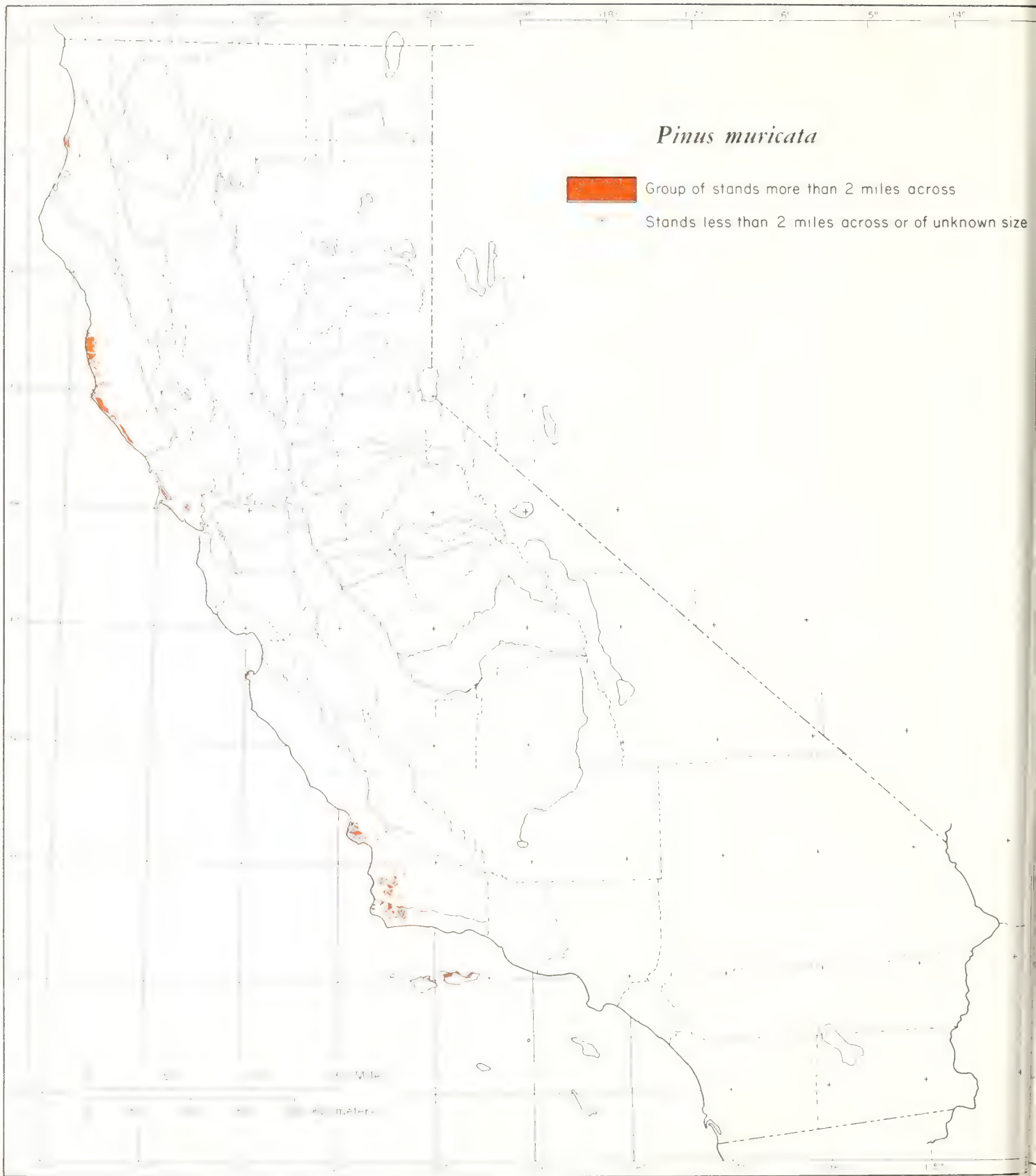
Map 49


Pinus monophylla
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data
50 Miles
50 Kilometers

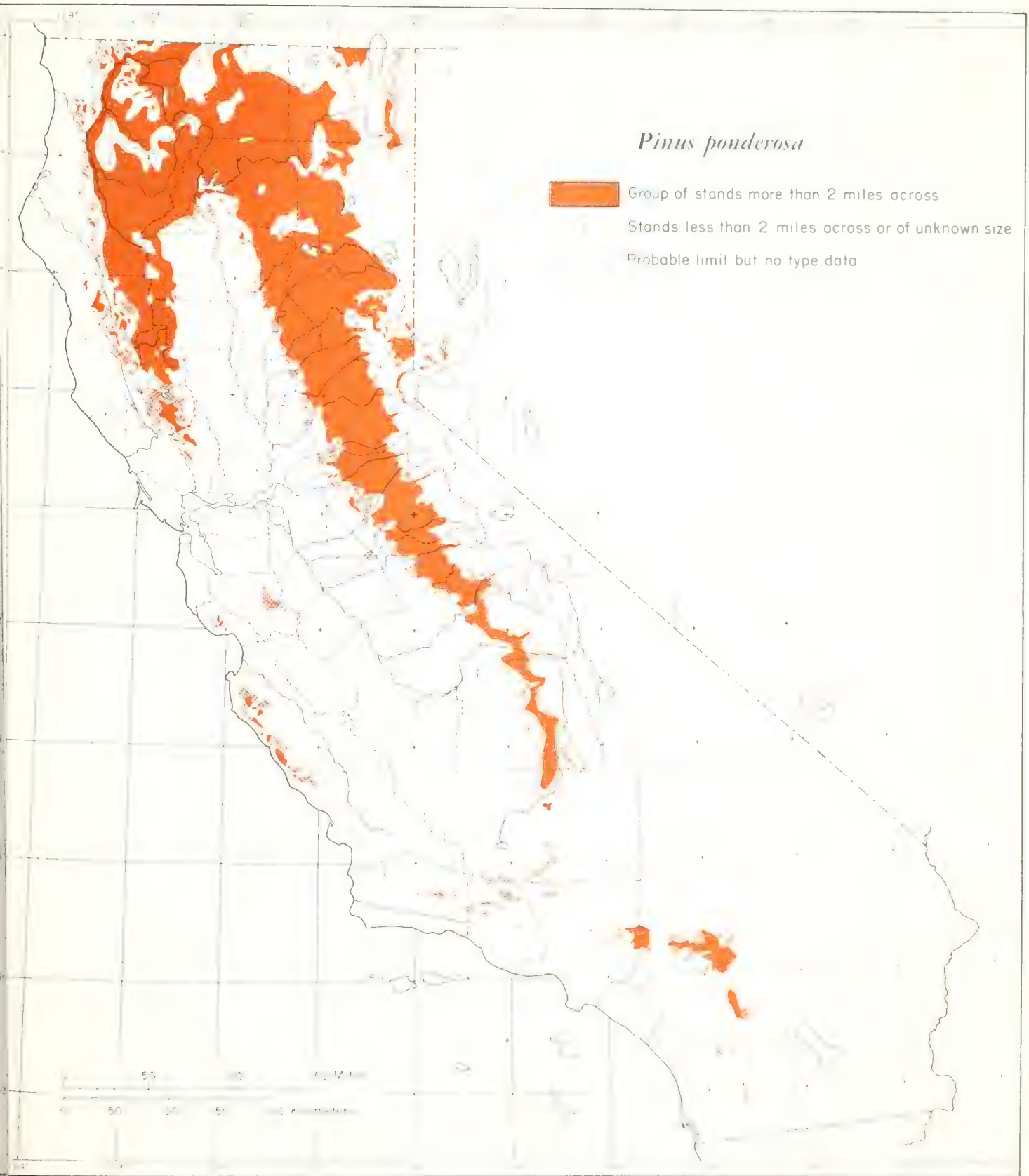
Map 50


Pinus monticola
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data

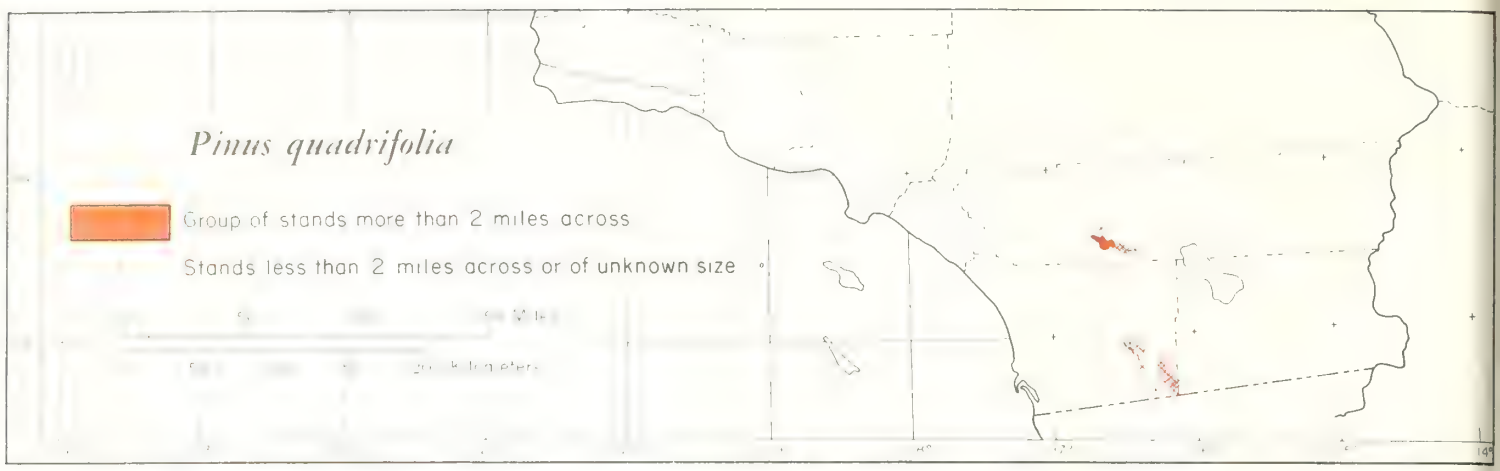
Map 51

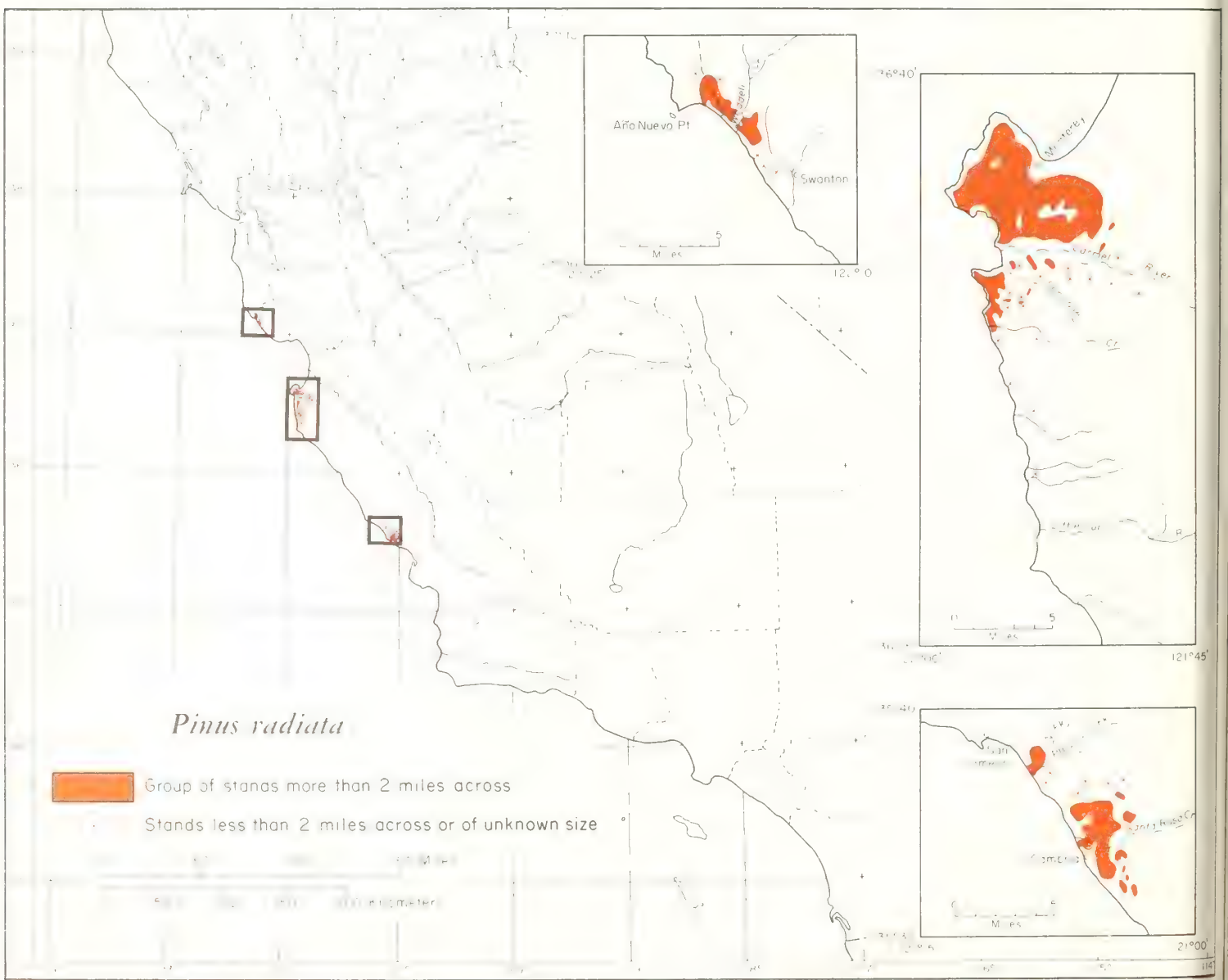

Pinus muricata
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size

Map 52

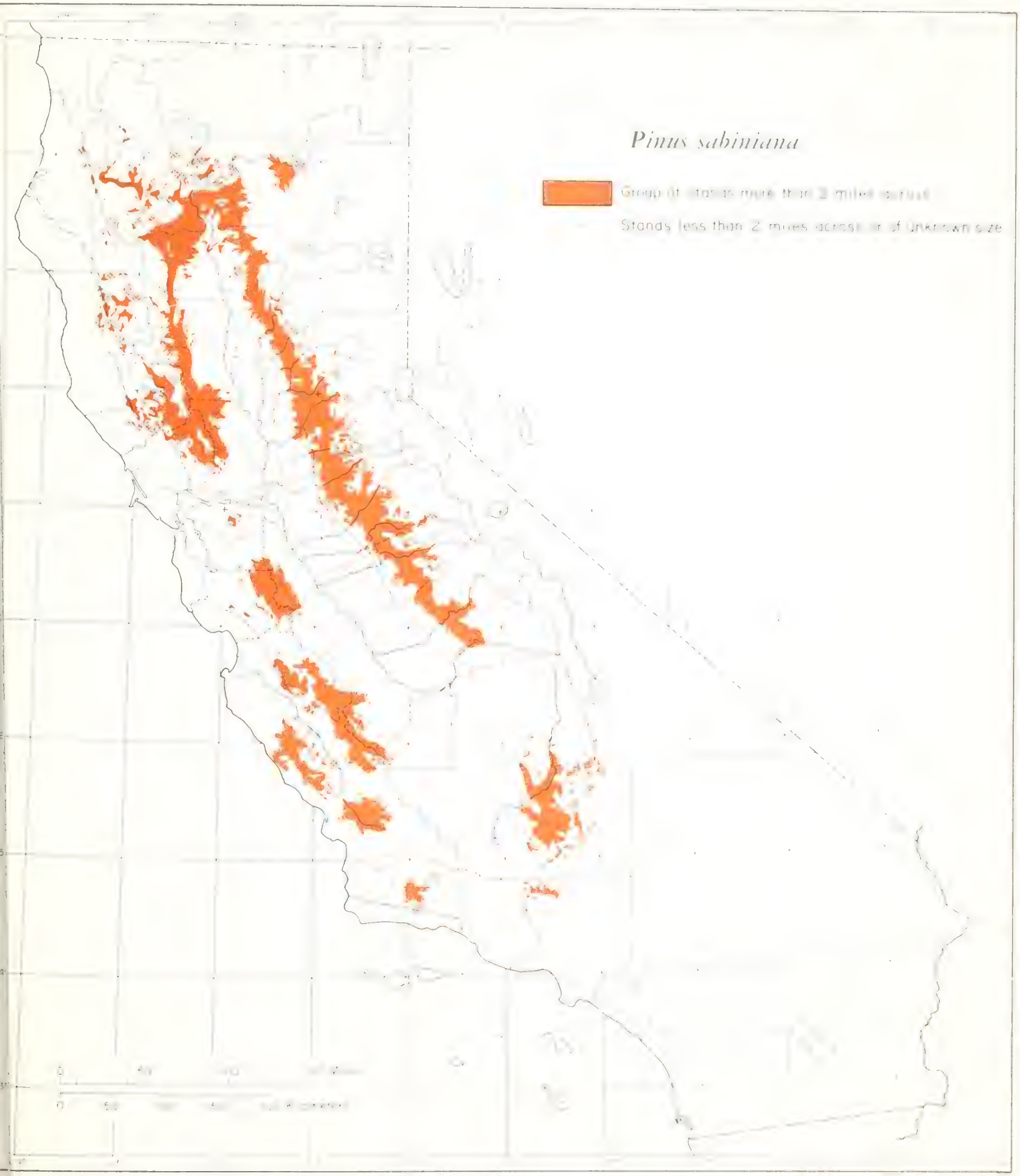

*Pinus ponderosa*
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data

Map 53

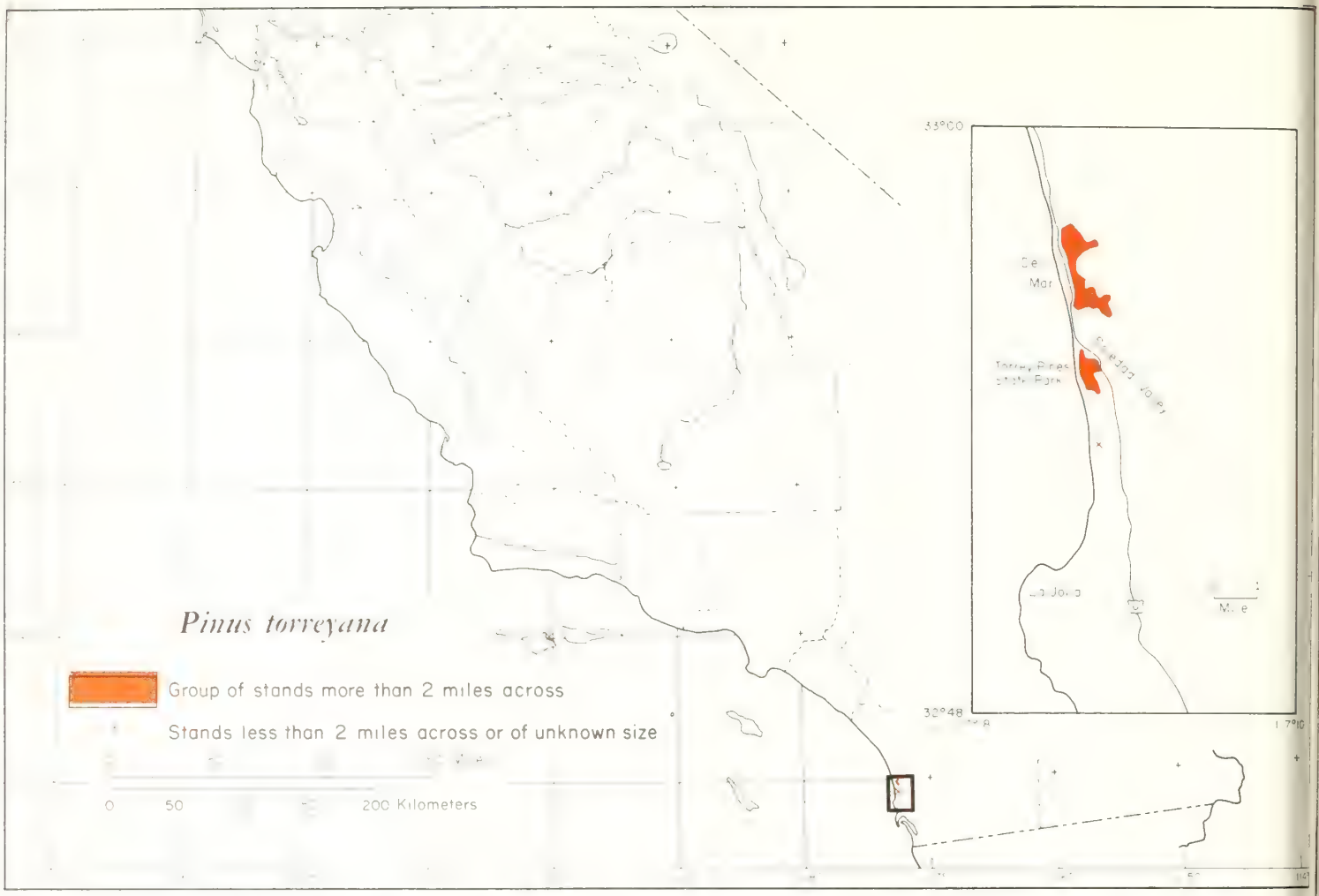


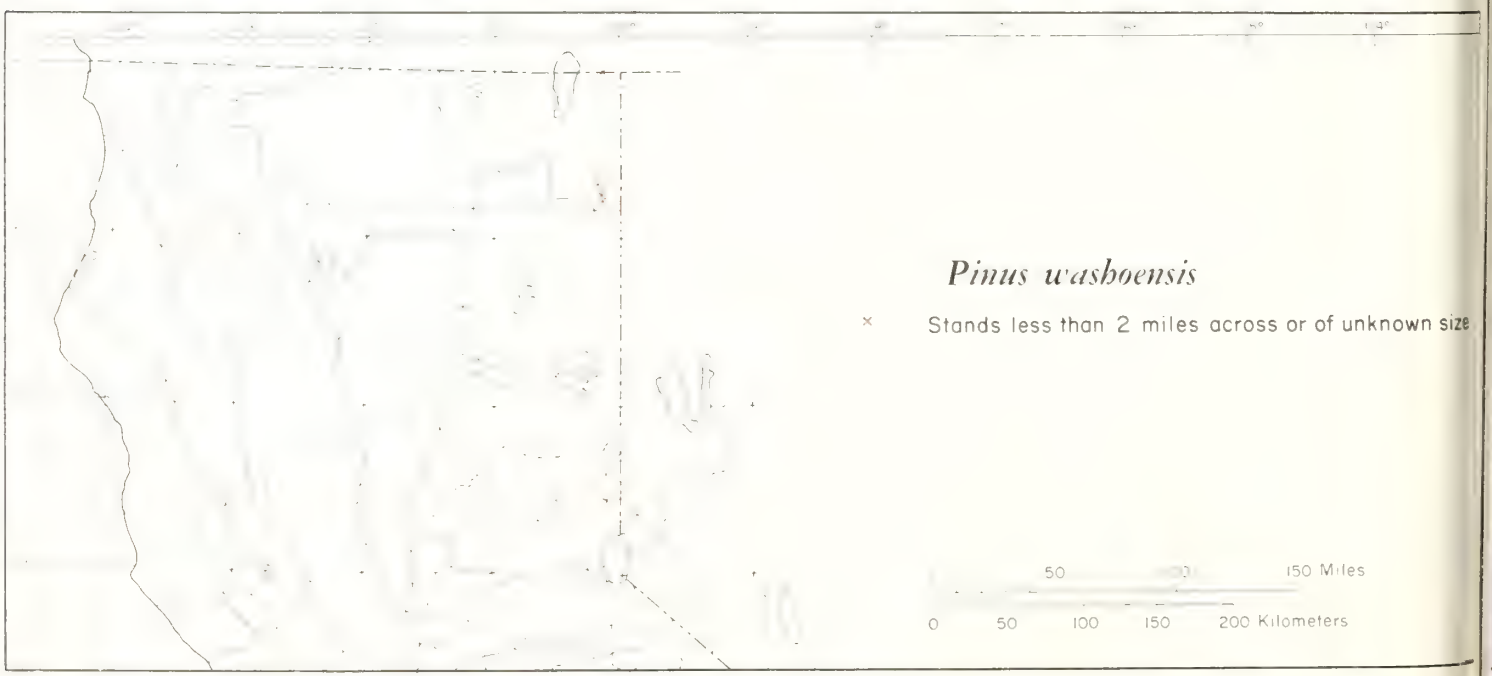


Año Nuevo Pt
Swanton
Pinus radiata
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size

Map 54 (top) Map 55 (bottom)

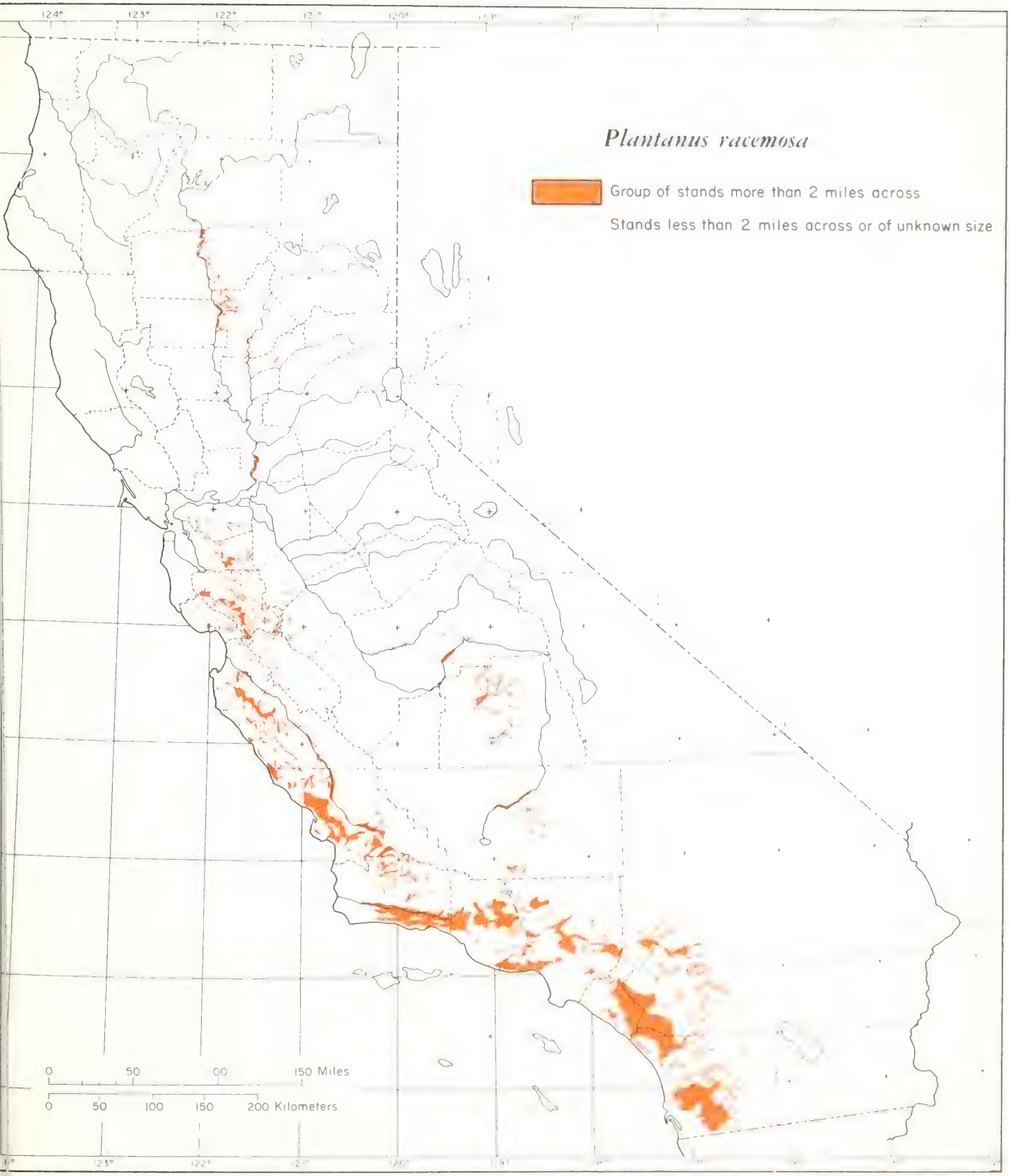

Pinus sabiniana
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size

Map 56

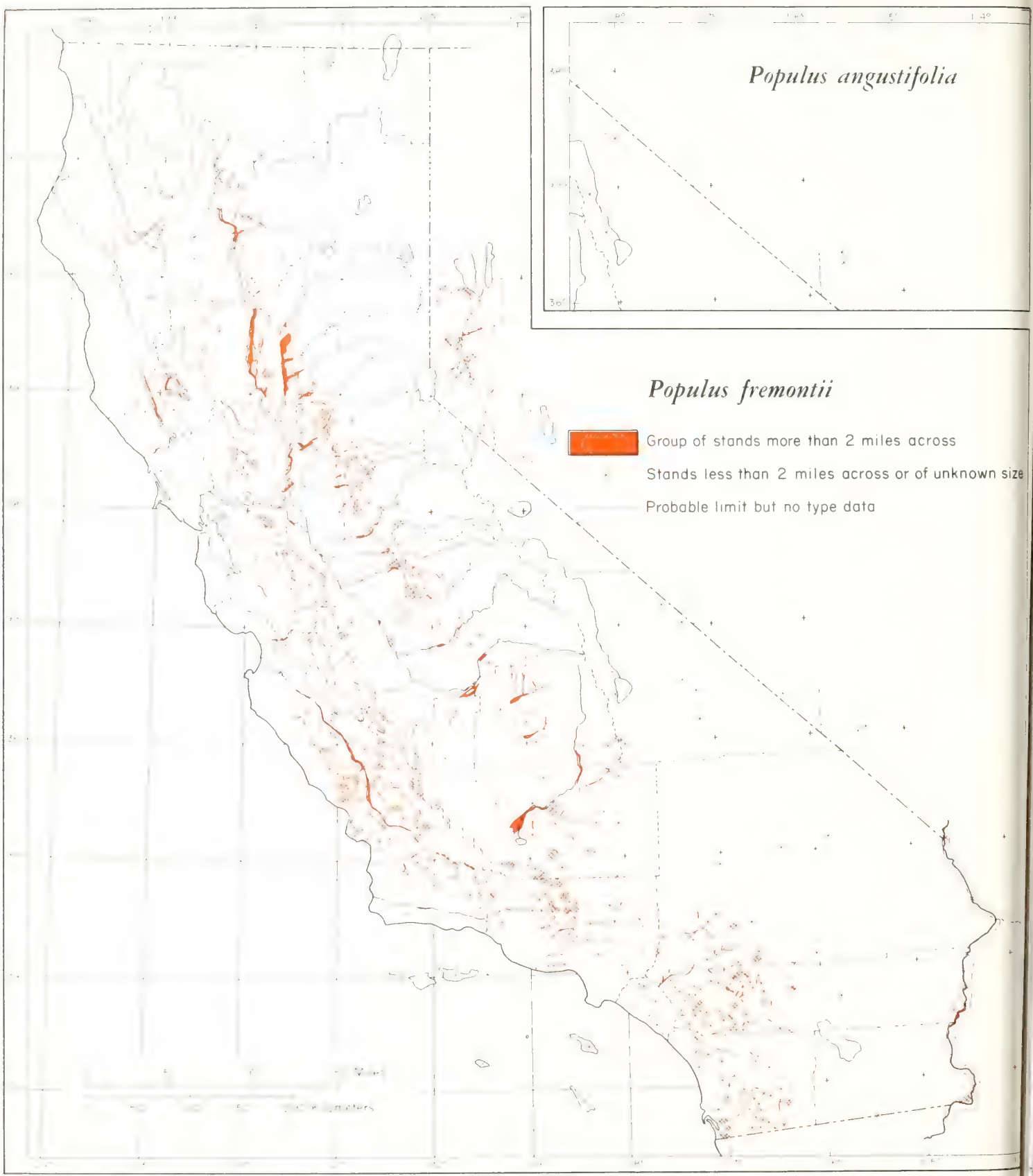


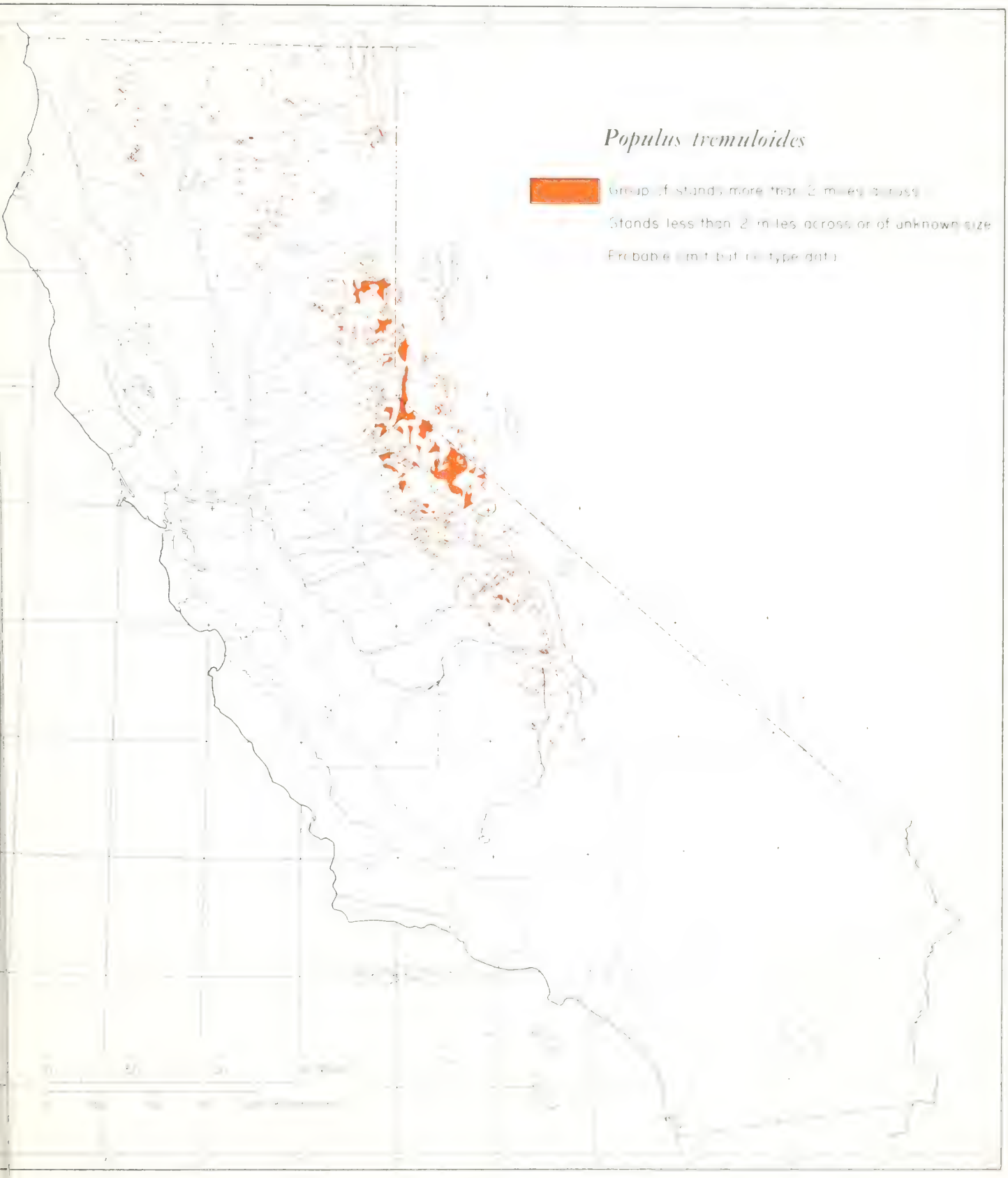

Map 57 (top) Map 58 (bottom)


Plantanus racemosa
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
0 50 00 150 Miles
0 50 100 150 200 Kilometers

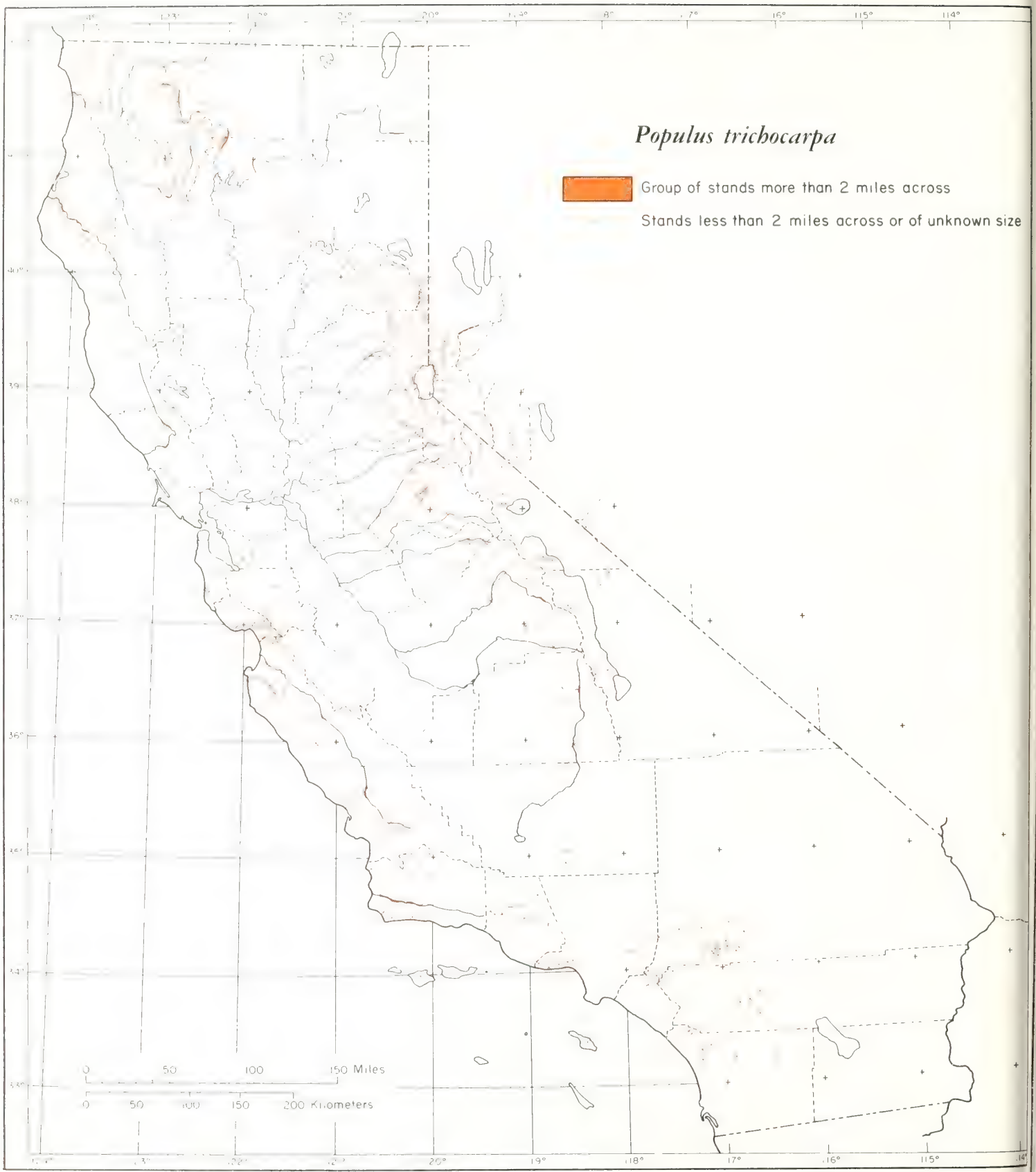
Map 59


Populus angustifolia
Populus fremontii
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data

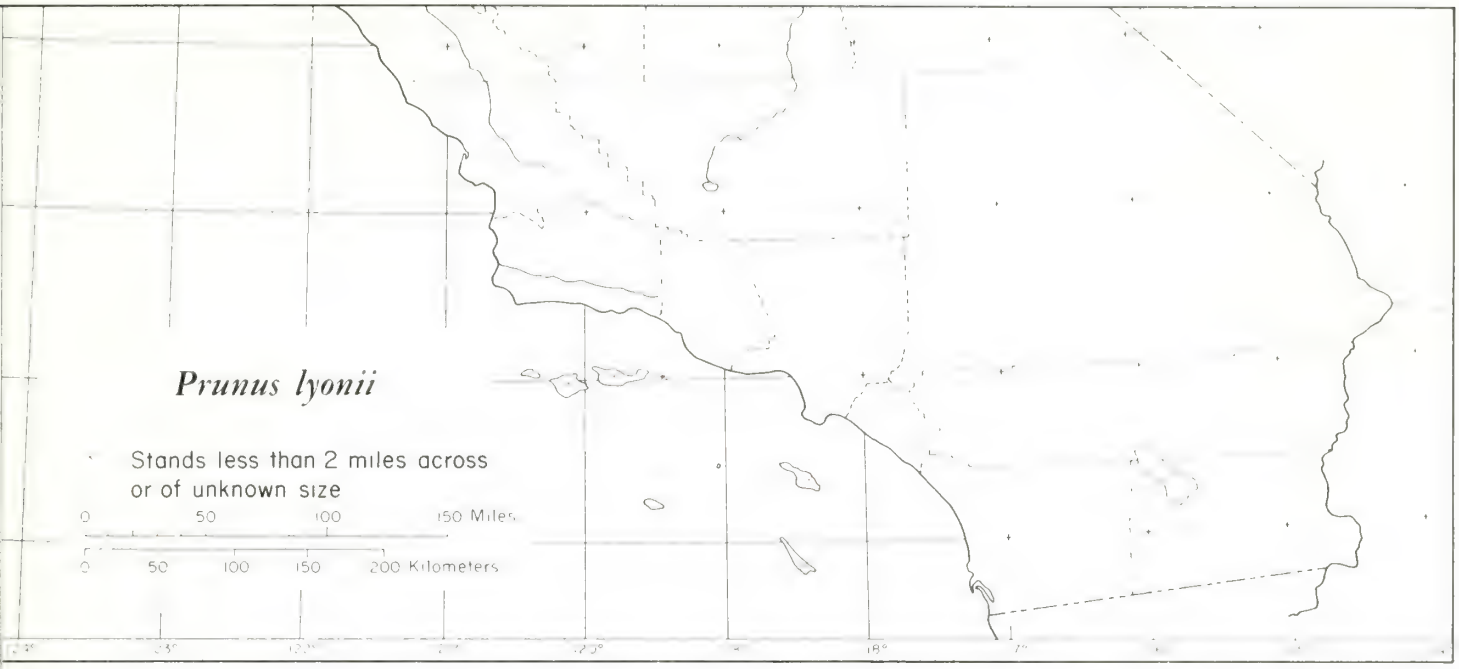
Map 60 (top)  Map 61 (bottom)

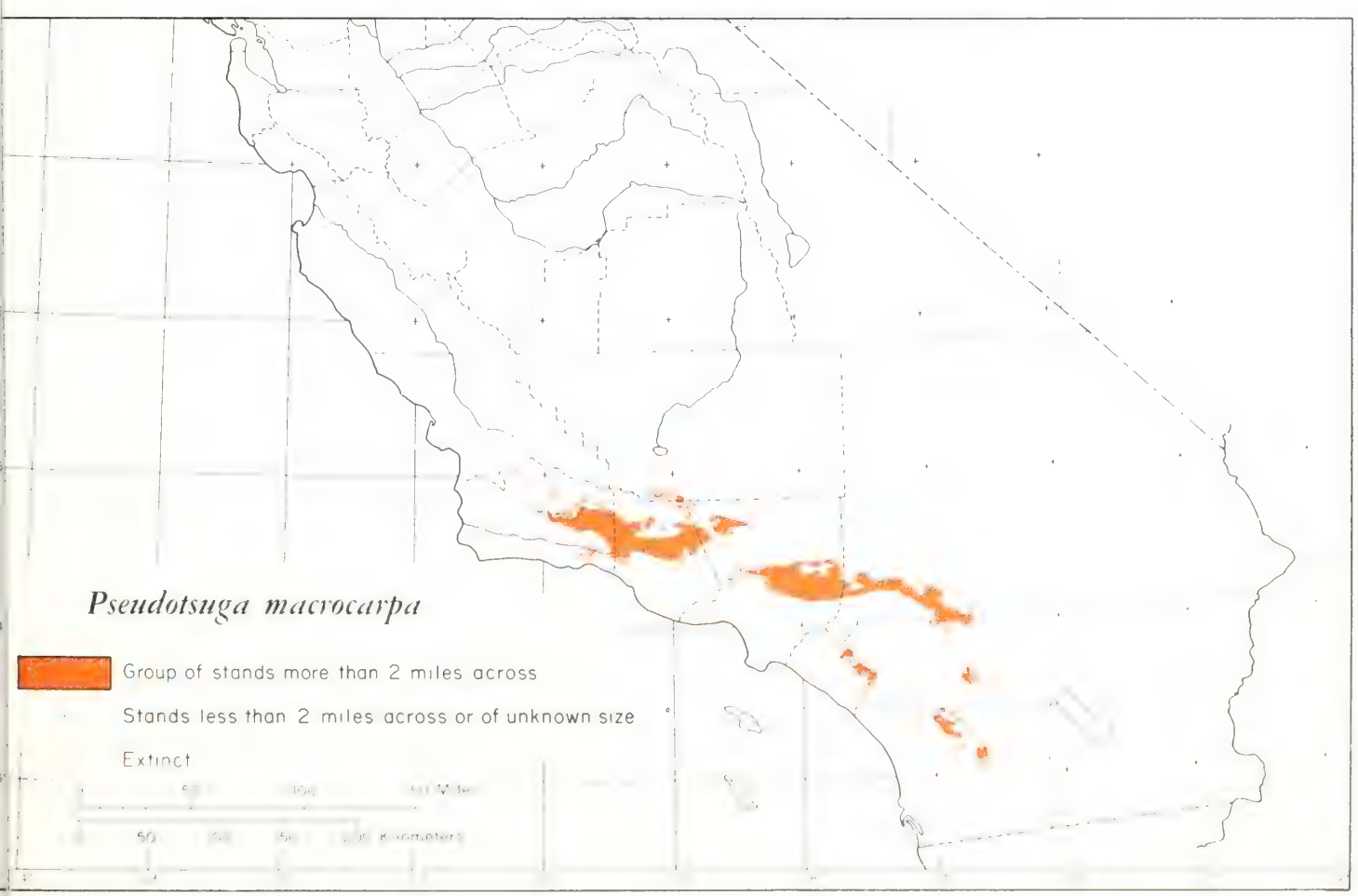

Populus tremuloides
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data

Map 62

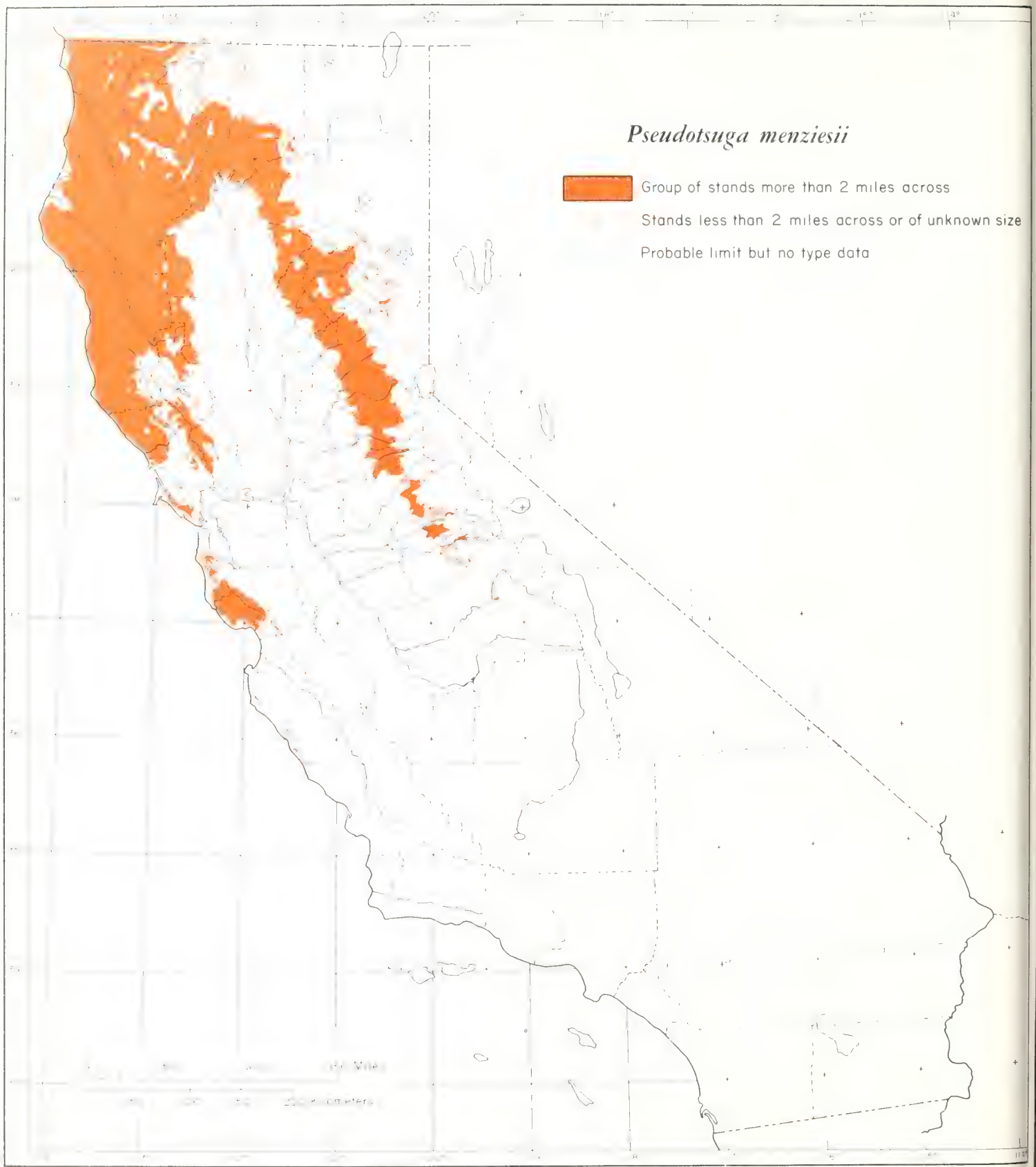

Populus trichocarpa
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
0 50 100 150 Miles
0 50 100 150 200 Kilometers

Map 63





Pseudotsuga macrocarpa
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Extinct

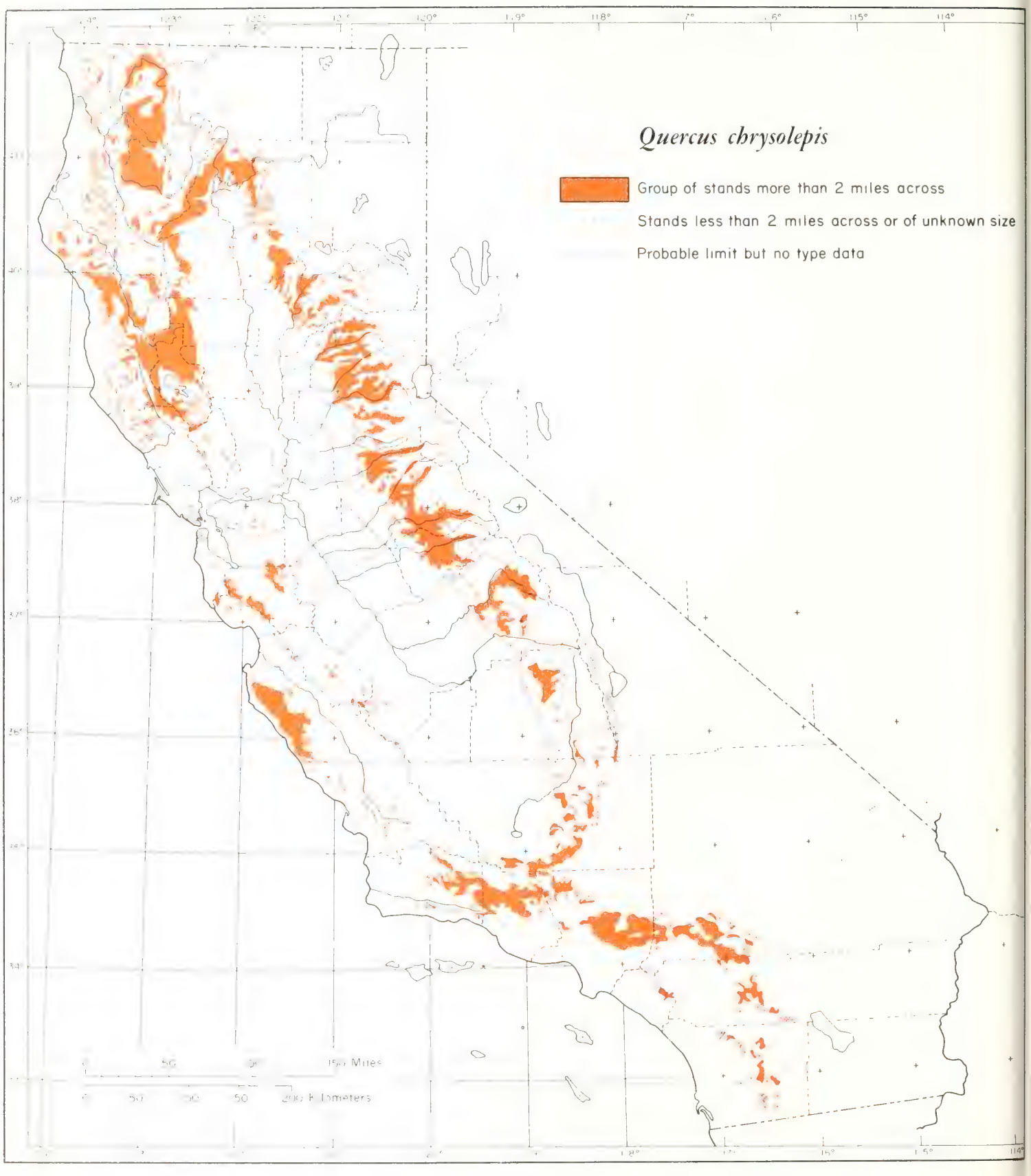
Map 64 (top) Map 65 (bottom)


Pseudotsuga menziesii
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data

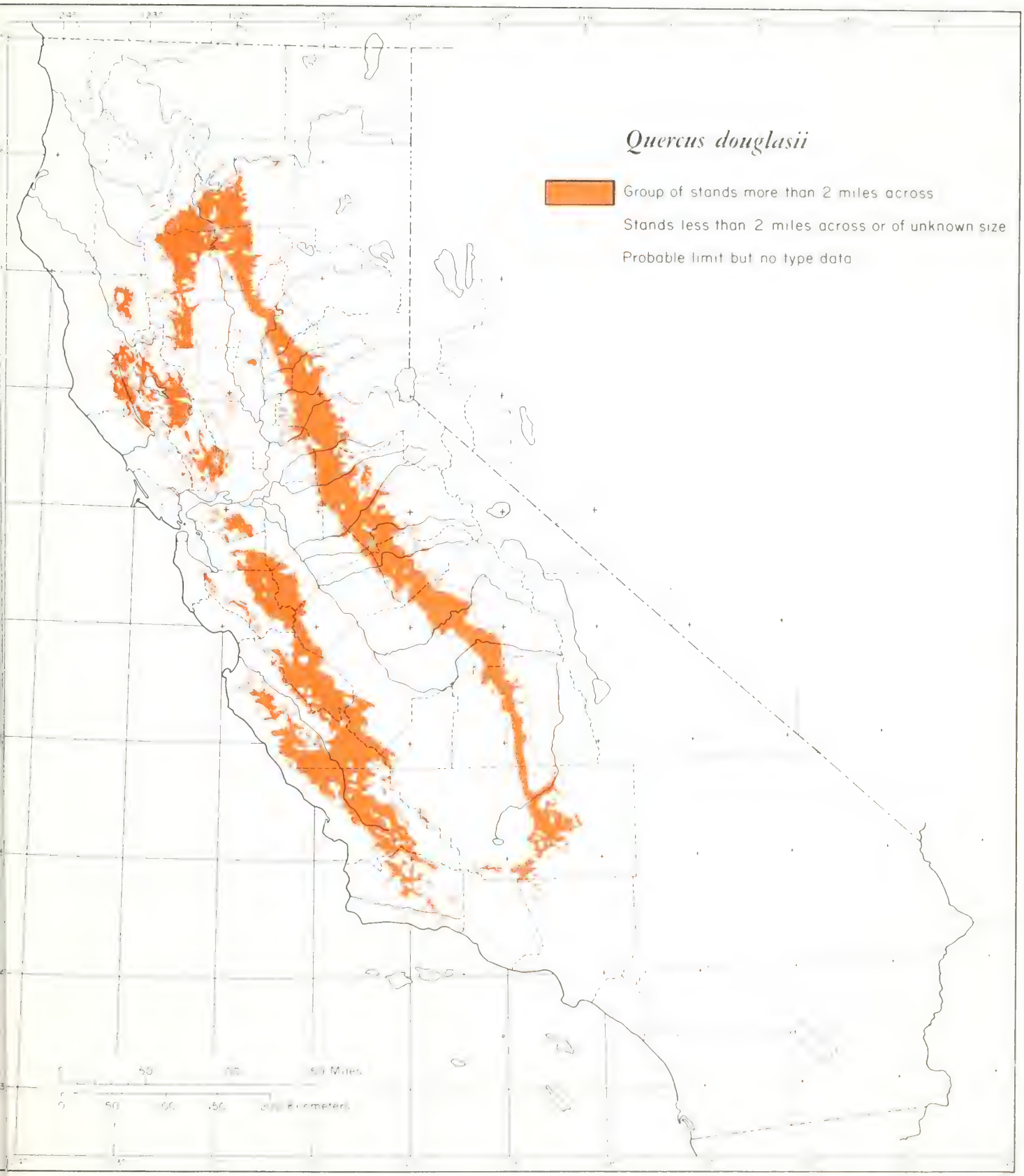
Map 66

Quercus agrifolia
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data
Extinct

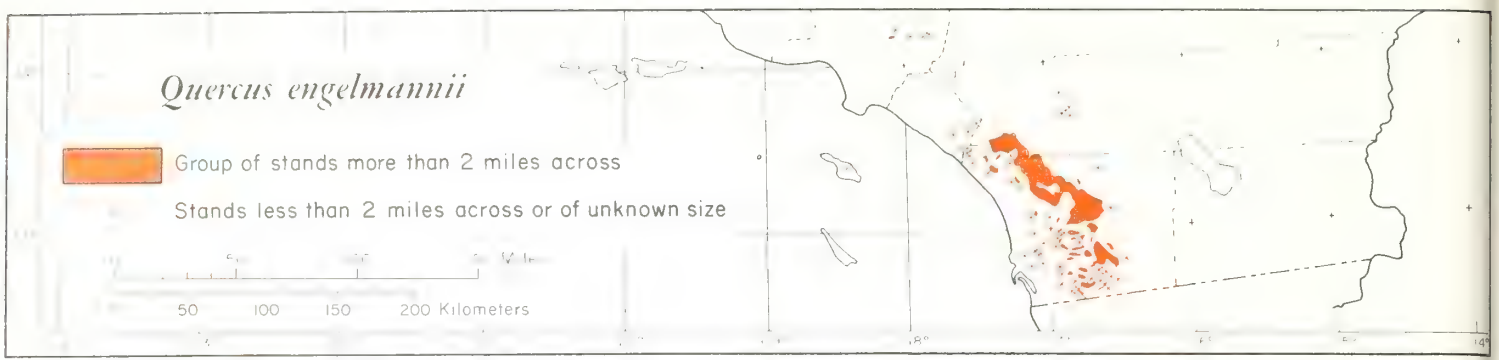
Map 67 (bottom) Map 68 (top)

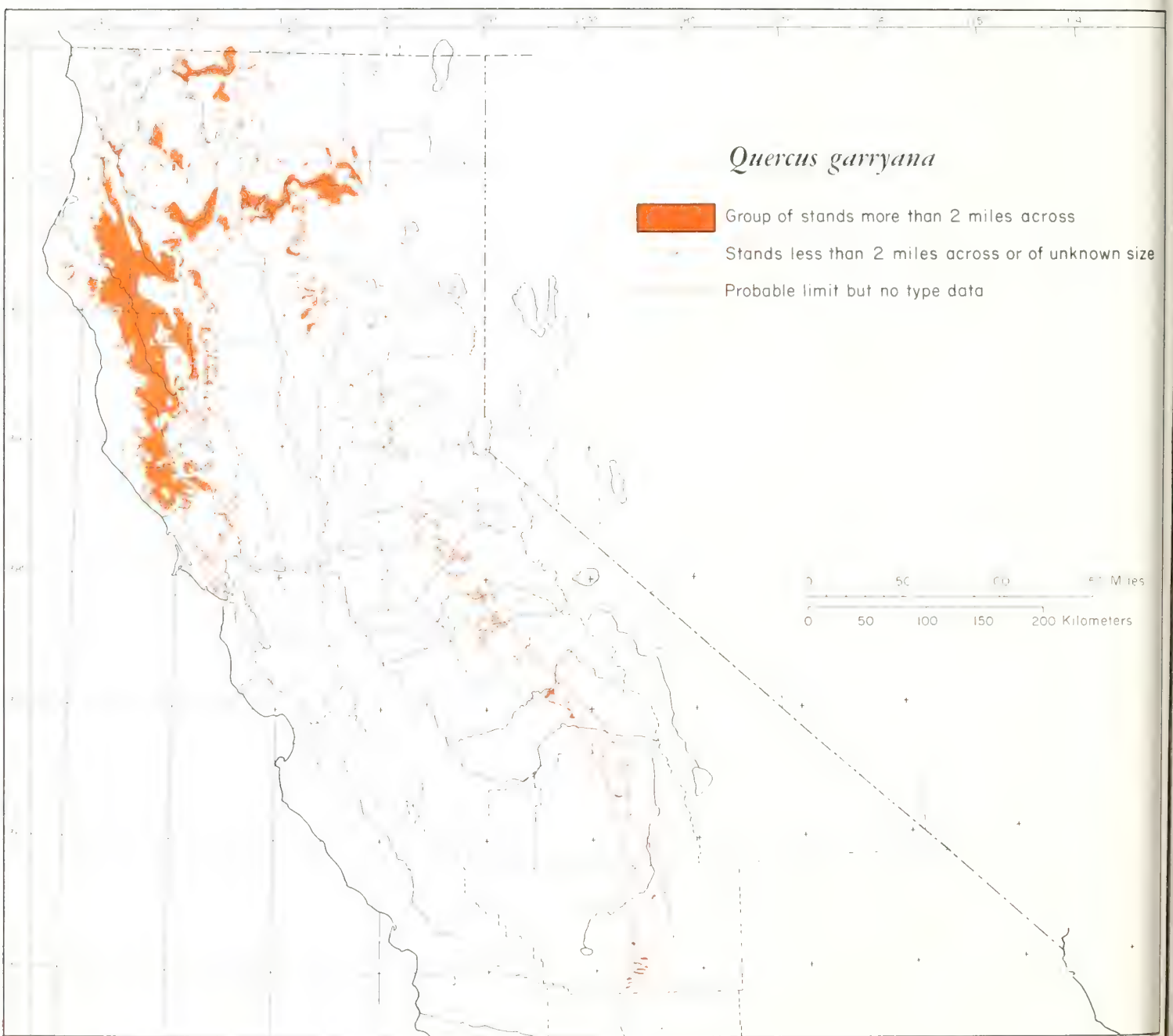

Quercus chrysolepis
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data

Map 69

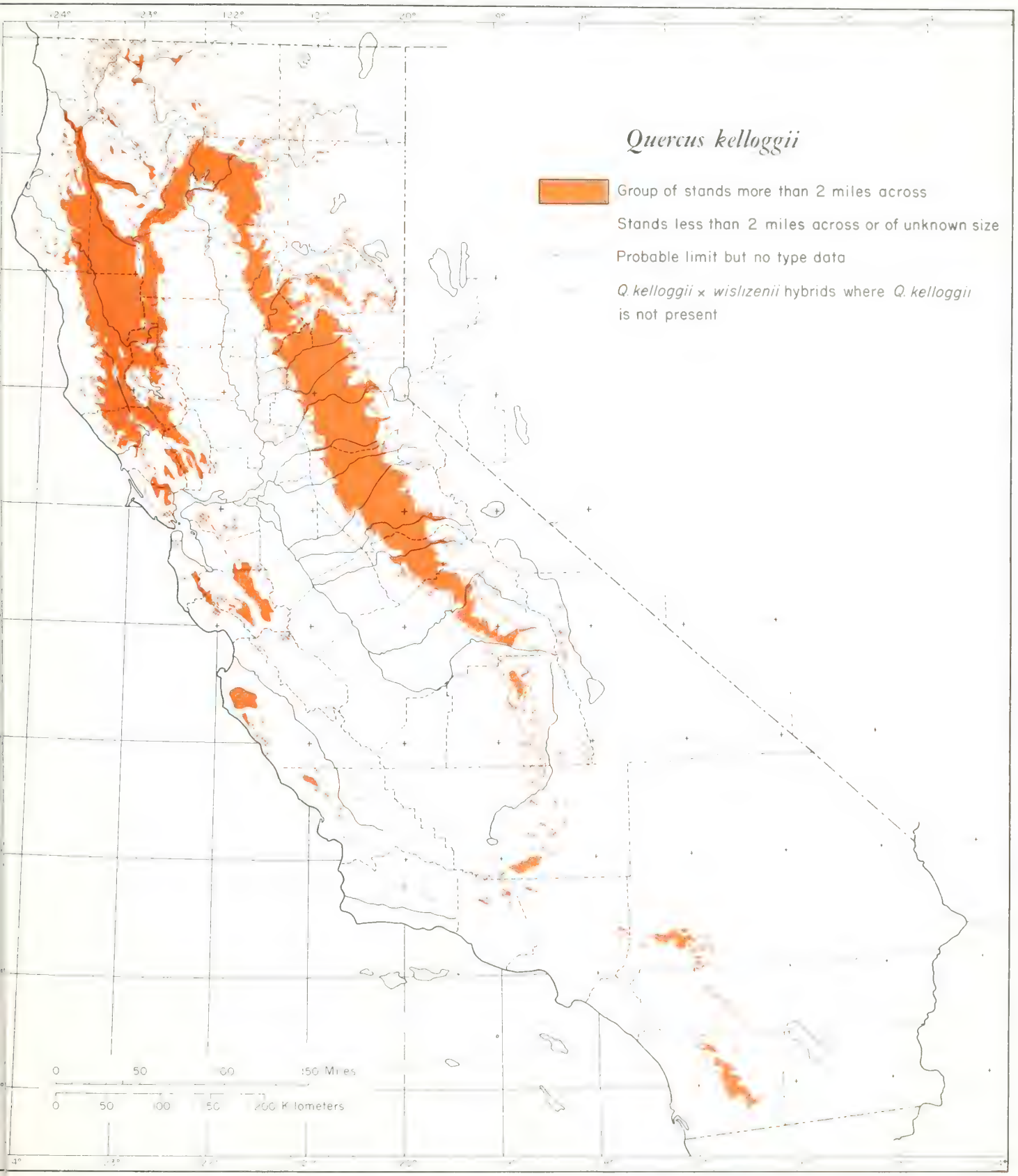

Quercus douglasii
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data

Map 70

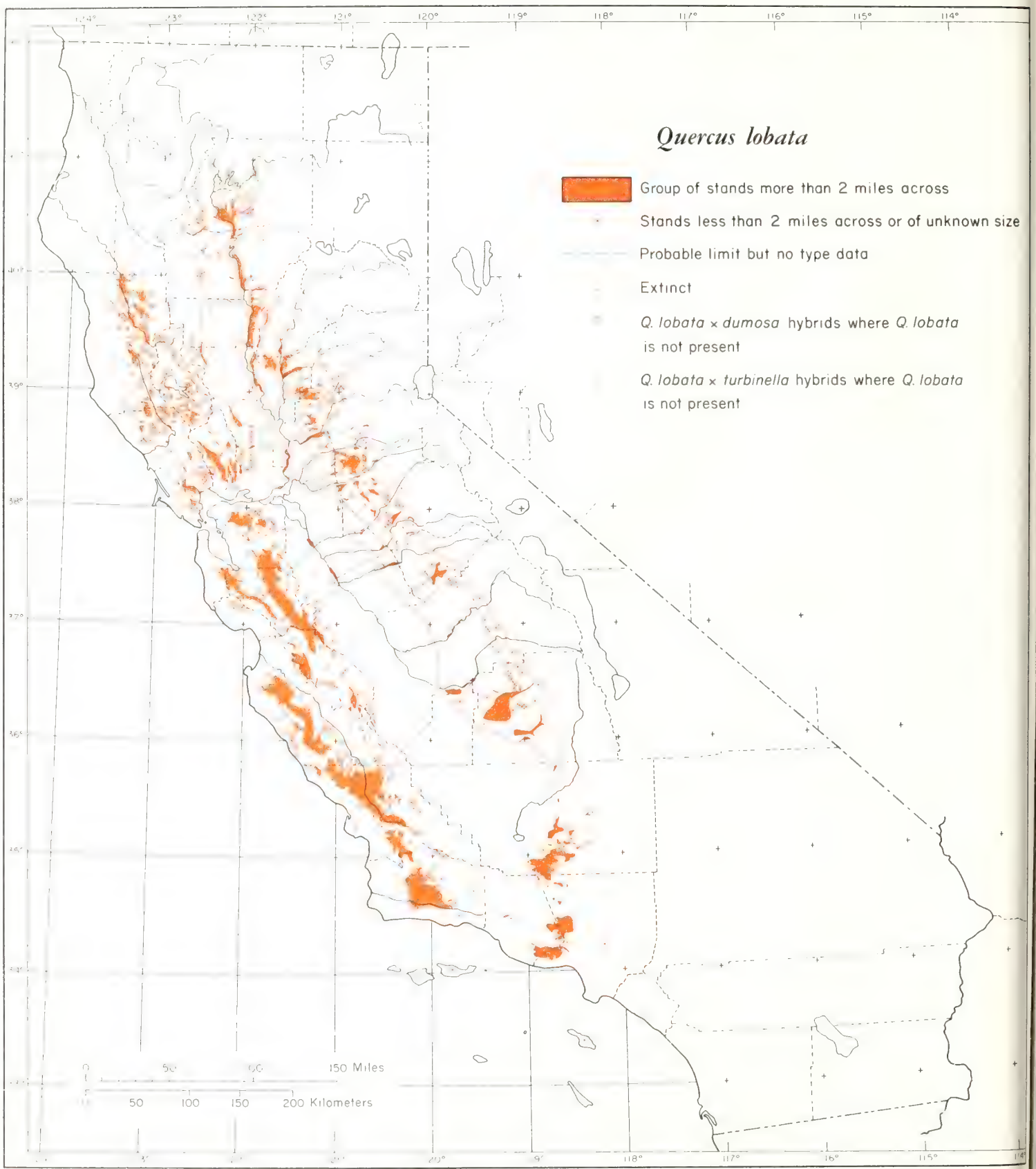

Quercus engelmannii
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
50 100 150 200 Kilometers


Quercus garryana
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data
0 50 100 150 200 Kilometers

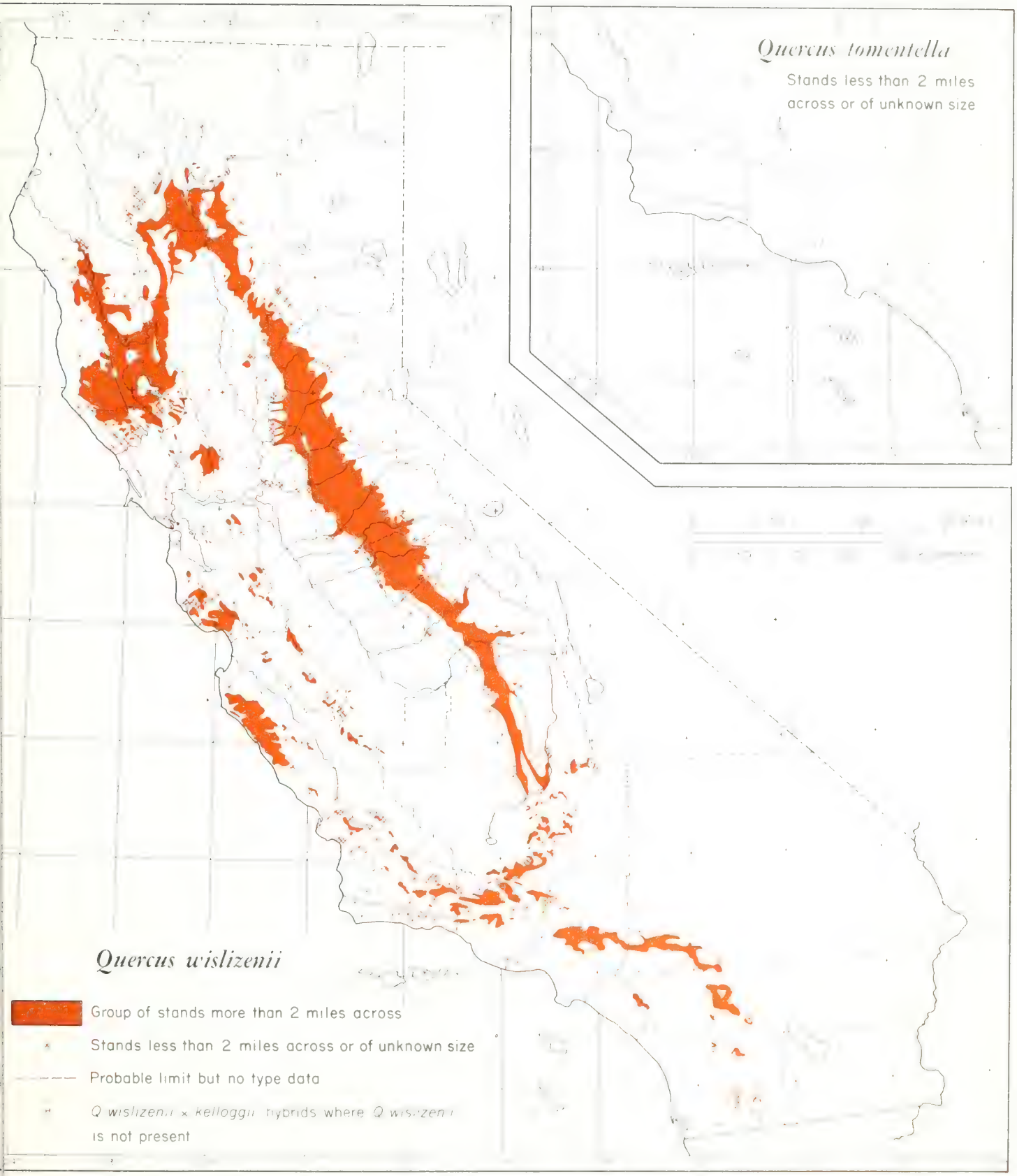
Map 71 (top) Map 72 (bottom)


Quercus kelloggii
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data
Q. kelloggii × wislizenii hybrids where Q. kelloggii is not present
0 50 100 150 Miles
0 50 100 150 200 Kilometers

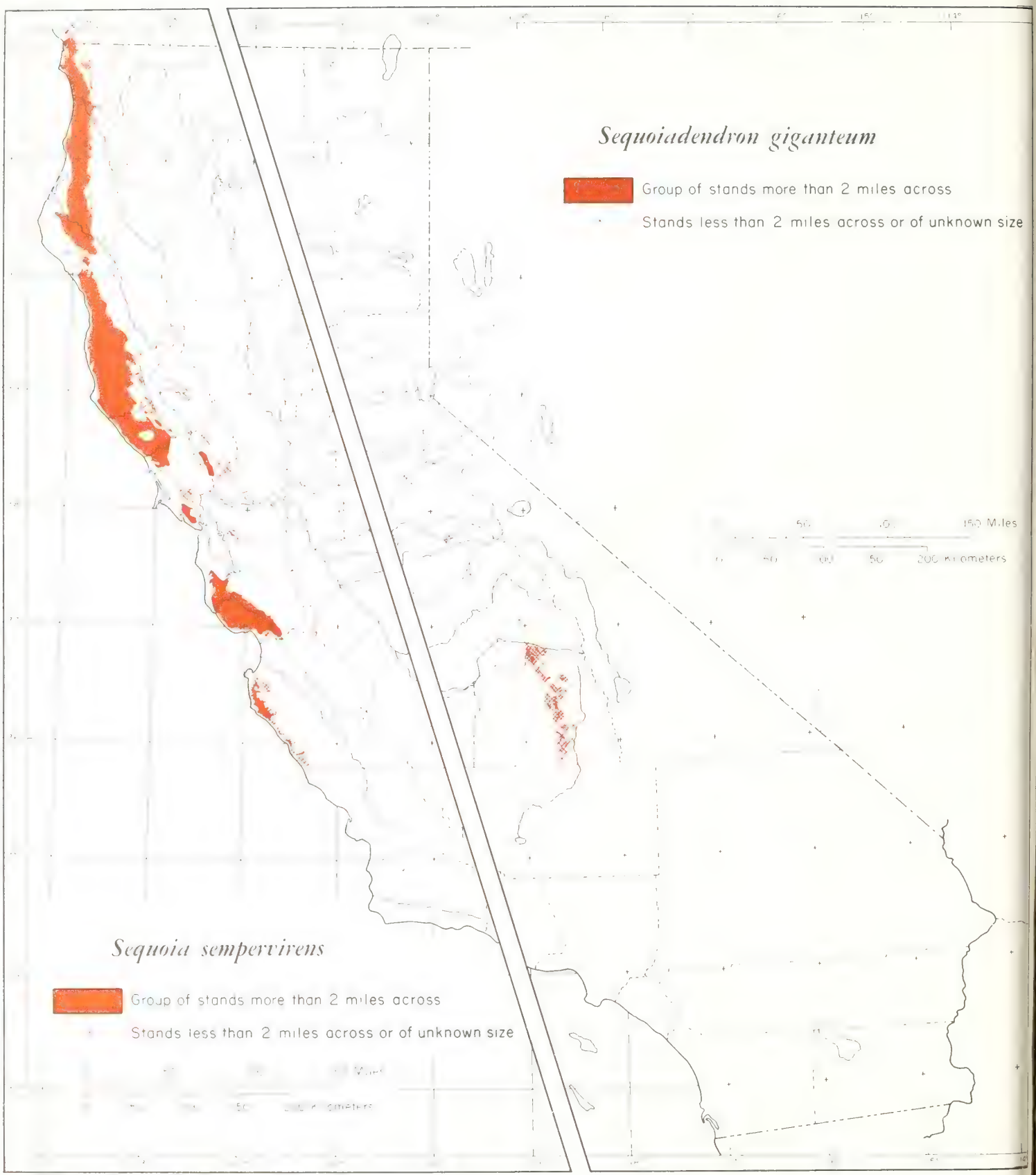
Map 73


Quercus lobata
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data
Extinct
Q. lobata x dumosa hybrids where Q. lobata is not present
Q. lobata x turbinella hybrids where Q. lobata is not present
0 50 100 150 Miles
50 100 150 200 Kilometers

Map 74

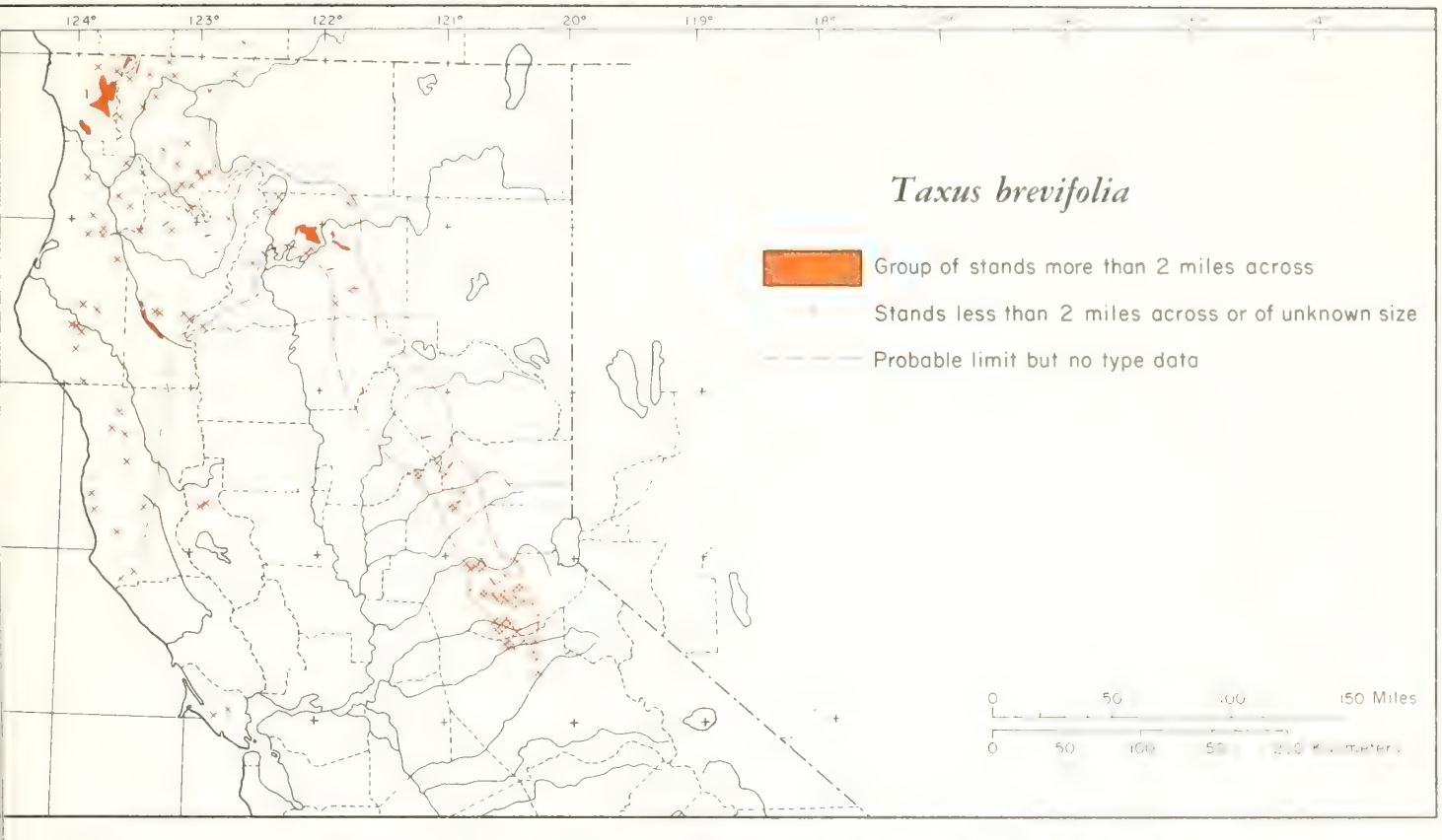

Quercus tomentella
Stands less than 2 miles across or of unknown size
Quercus wislizenii
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data
Q wislizenii x kelloggii hybrids where Q wislizenii is not present

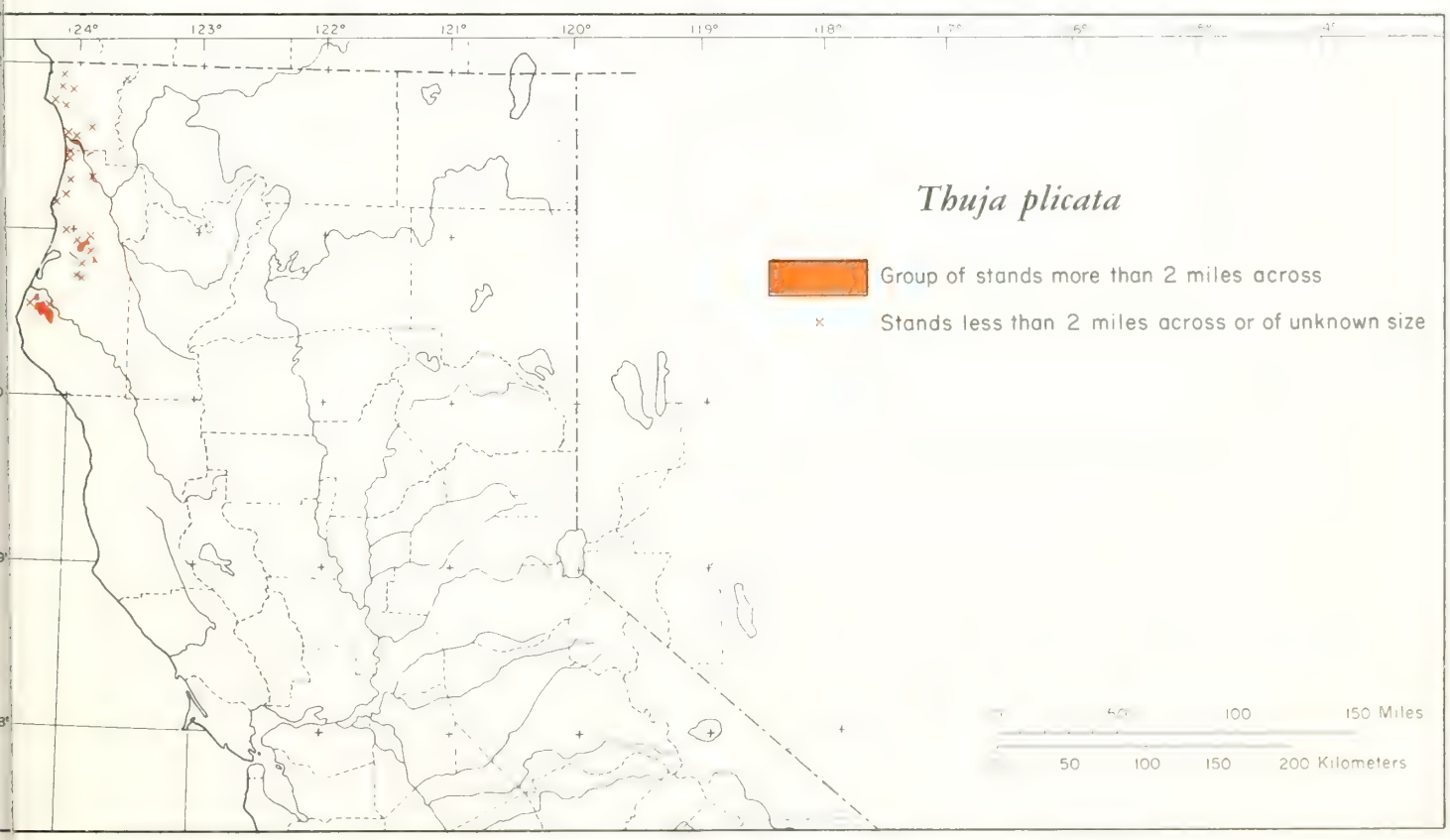
Map 75 (top)  Map 76 (bottom)


Sequoiadendron giganteum
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Sequoia sempervirens
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size

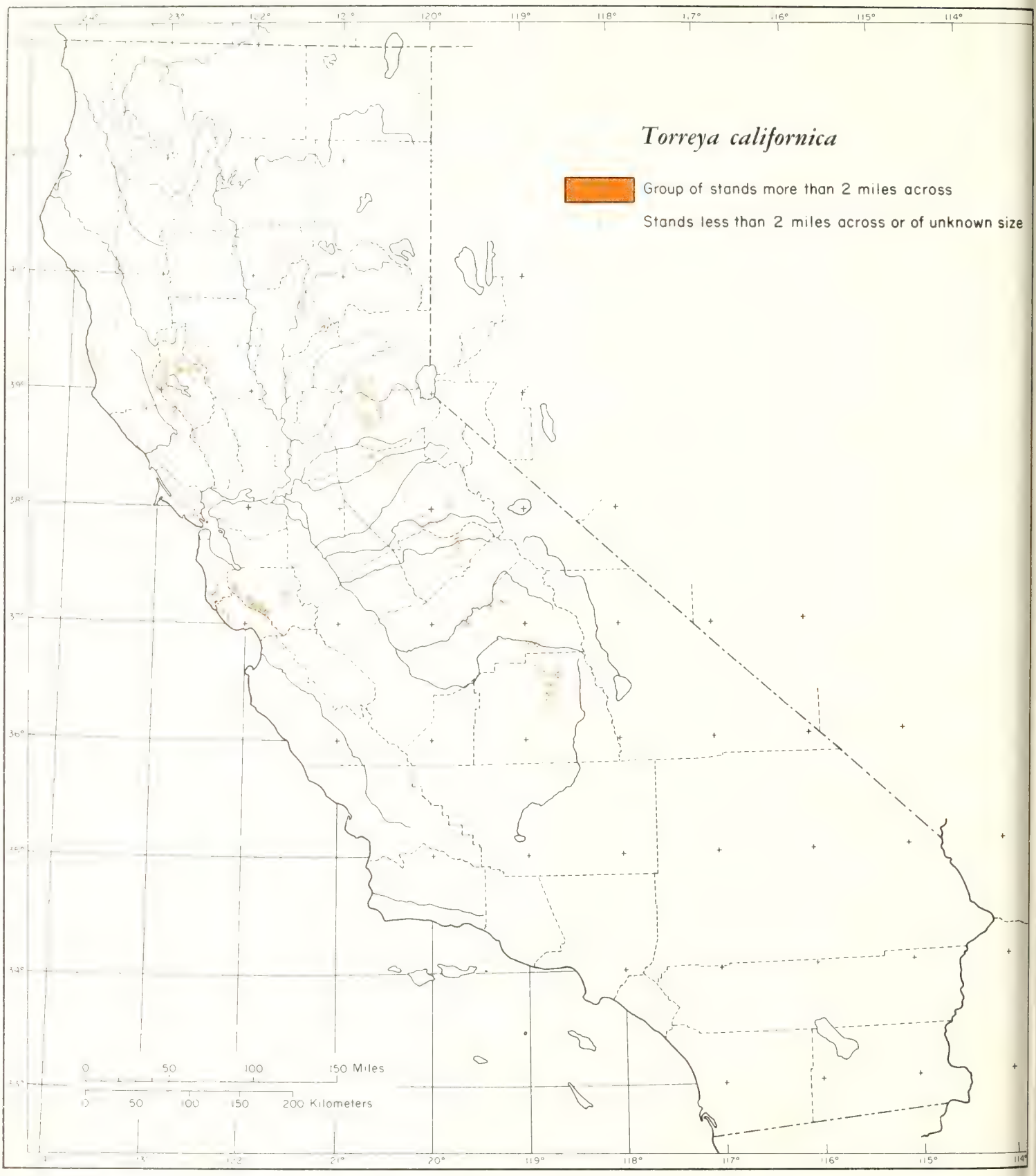
Map 77

Map 78



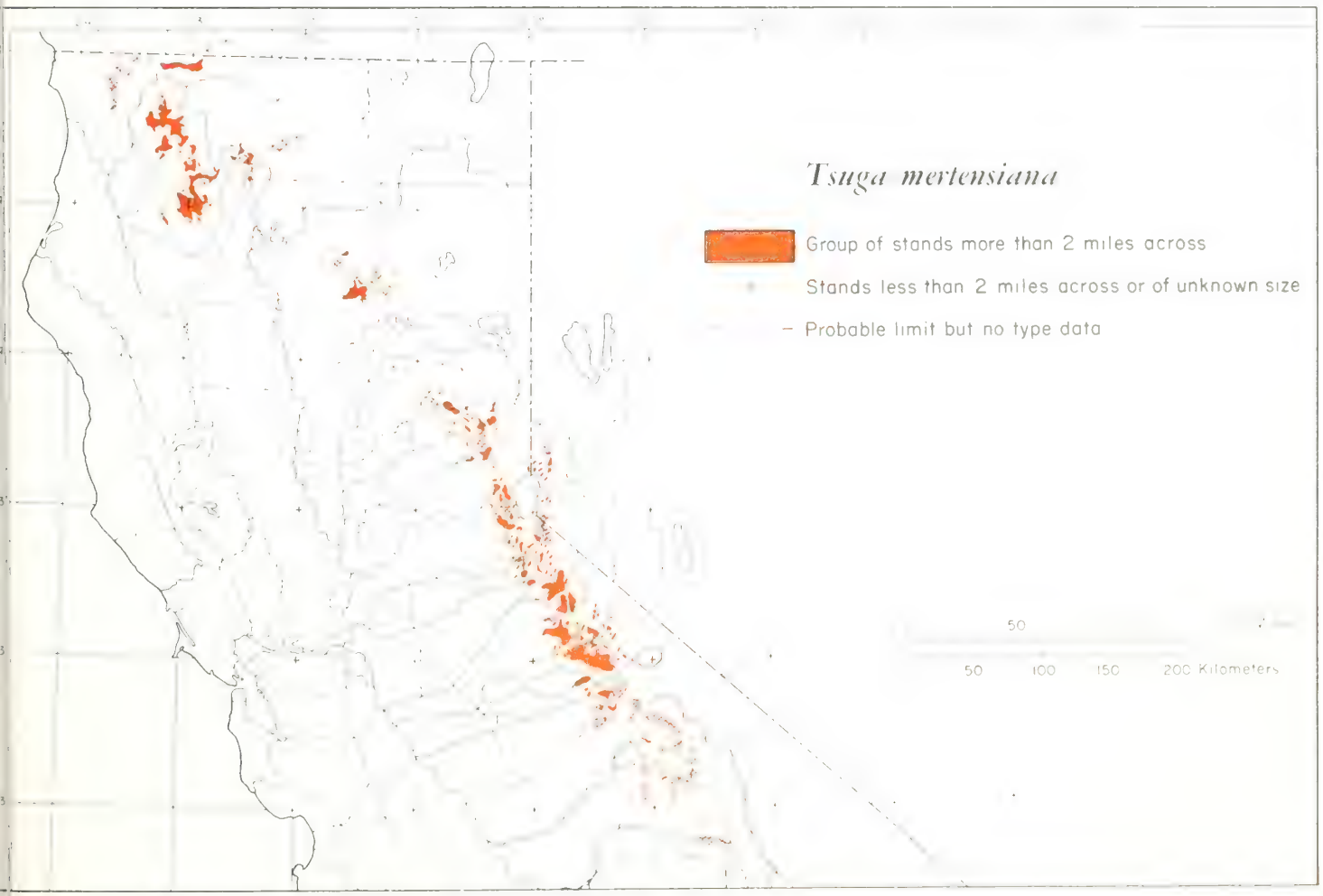




Map 79 (top)  Map 80 (bottom)

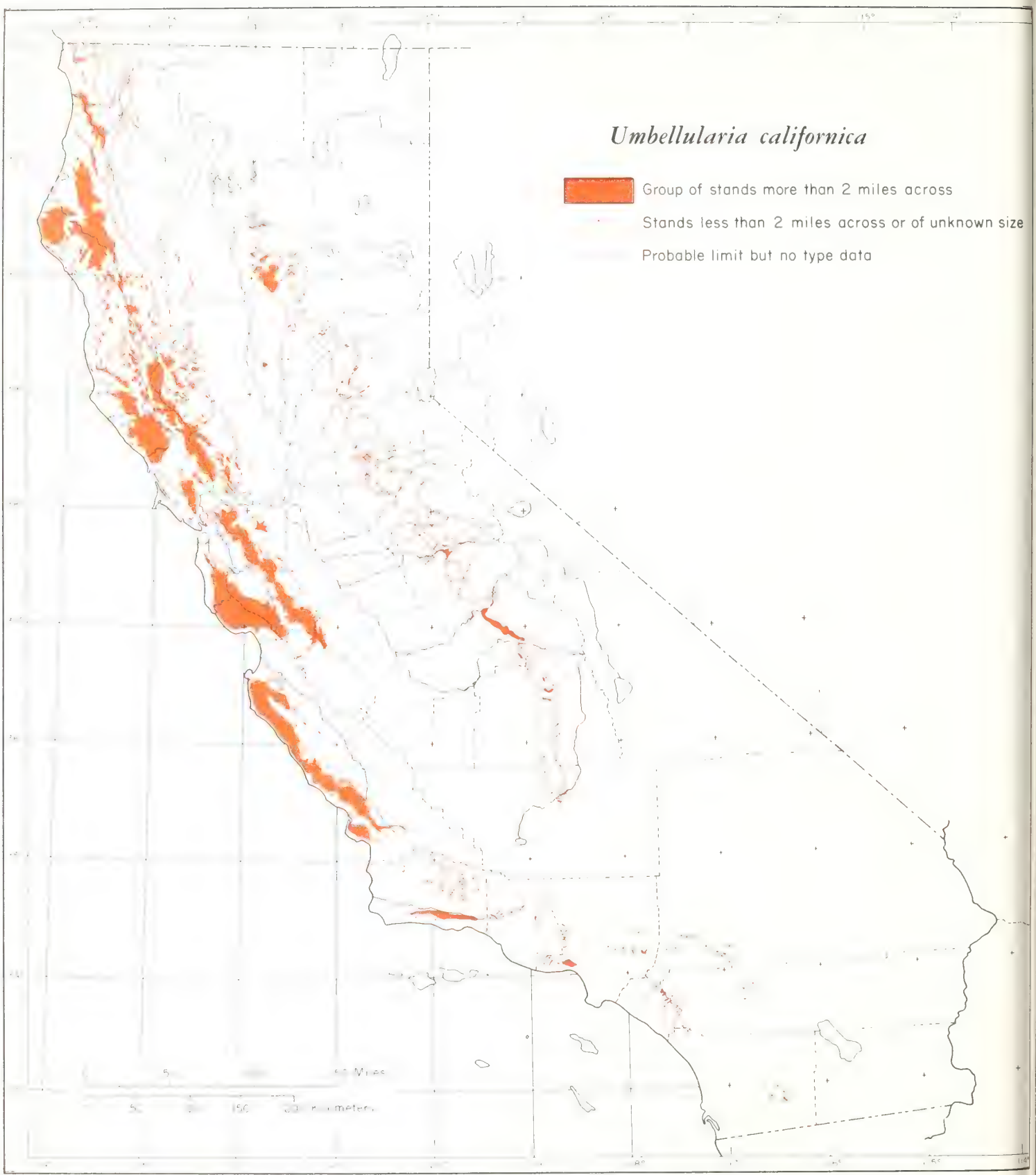

Torreya californica
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
0 50 100 150 Miles
0 50 100 150 200 Kilometers

Map 81

Tsuga heterophylla
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data
0 50 200 Kilometers


Tsuga mertensiana
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data
50
50 100 150 200 Kilometers

Map 82 (top) Map 83 (bottom)


Umbellularia californica
Group of stands more than 2 miles across
Stands less than 2 miles across or of unknown size
Probable limit but no type data

Map 84

# GEOGRAPHIC LOCATION OF PLACE NAMES

| *Name* | *Latitude (N)* | *Longitude (W)* |
|---|---|---|
| Adin Pass | 41°21' | 120°55' |
| Aetna Springs | 38°39' | 122°29' |
| Alder Creek | 35°52' | 121°24' |
| Amador City | 38°25' | 120°49.5' |
| Anastasia Canyon | 36°20.5' | 121°34' |
| Anchor Bay | 38°48' | 123°34.5' |
| Anderson Valley | 39°00' | 123°22' |
| Antelope Valley | 34°45' | 118°15' |
| Applegate | 39°00' | 120°59.5' |
| Arroyo Seco | 36°16' | 121°23' |
| Asbill Creek | 39°55.5' | 123°21.5' |
| Ash Creek | 40°28' | 122°00' |
| Atlas Peak | 38°27' | 122°15.5' |
| Atwell Grove | 36°28' | 118°40.5' |
| Avila | 35°11' | 120°44' |
| Bald Mt. (Nev.) | 41°50' | 119°37.5' |
| Bald Mt. Range | 39°36' | 120°06' |
| Banner | 33°04' | 116°33' |
| Banner Canyon | 33°05' | 116°34' |
| Basket Peak | 35°39' | 118°38.5' |
| Bautista Canyon | 33°36' | 116°44' |
| Bear Basin Butte | 41°48.5' | 123°44.5' |
| Ben Lomond Mt. | 37°06.5' | 122°09' |
| Big Creek | 37°12' | 119°15' |
| Big Meadow | 35°52.5' | 118°20.5' |
| Big River | 39°18' | 123°47' |
| Big Valley Mts. | 41°10' | 121°20' |
| Bill Little Spring | 35°25.5' | 119°50.5' |
| Black Butte (Glenn Co.) | 39°43.5' | 122°52.5' |
| Black Butte (Siskiyou Co.) | 41°22' | 122°21' |
| Black Rock Mt. | 40°12' | 123°00.5' |
| Blakes Fork, South Russian Creek | 41°17.5' | 122°59.5' |
| Blodgett Forest | 38°55' | 120°39.5' |
| Boca | 39°23' | 120°05.5' |
| Bolinas Ridge | 38°57.5' | 122°43' |
| Boonville | 39°00.5' | 123°22' |
| Bouquet Canyon | 34°30' | 118°27' |
| Box Springs Mts. | 33°58' | 117°17' |
| Breckenridge Mt. | 35°27' | 118°34.5' |
| Browns Creek | 40°35' | 122°55' |
| Brownsville | 39°28.5' | 121°16' |
| Brush Mt. | 34°53' | 119°13.5' |
| Buck Creek Ranger Station | 41°52.5' | 120°17.5' |
| Bully Choop | 40°33.5' | 122°46' |
| Burney Springs | 40°47' | 121°37.5' |
| Burton Mesa | 34°44' | 120°34' |
| Butte Lake | 40°34' | 121°17.5' |
| Cabin Creek | 37°42.5' | 118°15' |
| Calaveras Big Trees State Park | 38°17' | 120°18.5' |
| Caliente | 35°17.5' | 118°37.5' |
| Caliente Mt. | 35°02' | 119°45.5' |
| Callahan | 41°18.5' | 122°48' |
| Canyon Creek | 40°56' | 123°01' |
| Canyon Creek Lakes | 40°58.5' | 123°01.5' |
| Carmel Valley | 36°30' | 121°45' |
| Cascade Canyon | 34°12.5' | 117°39' |
| Castle Crags | 41°11' | 122°21' |
| Castle Lake | 41°13.5' | 122°23' |
| Castle Peak | 39°22' | 120°21' |
| Cedar Basin | 40°11' | 122°59' |
| Cedar Mt. | 37°33.5' | 121°36.5' |
| Cedar Pass | 41°34' | 120°16' |
| Cedar Roughs | 38°34' | 122°18' |
| Cedros Island (Mexico) | 28°10' | 115°15' |
| Chariot Canyon | 33°03' | 116°33' |
| Cherry Spring | 35°21.5' | 119°47' |
| Chetco River (Ore.) | 42°05' | 124°12' |
| Chews Ridge | 36°18.5' | 121°34' |
| Chiminea (Chiminaes) Canyon | 34°46.5' | 119°58.5' |
| Clark Mts. | 35°32' | 115°35' |
| Clear Creek | 36°23' | 120°43' |
| Clover Creek | 40°41' | 122°00' |
| Cone Peak | 36°03' | 121°29.5' |
| Converse Basin | 36°48' | 118°58' |
| Copernicus Peak | 37°21' | 121°37.5' |
| Corral Creek Campground | 35°51' | 118°27' |
| Cottonwood Creek | 41°59' | 122°38' |
| Courtland | 38°20' | 121°34' |
| Crater Lake (Ore.) | 42°55' | 122°05' |
| Cuesta Pass | 35°21' | 120°38' |
| Cummings | 39°50' | 123°37.5' |
| Cuyama Valley | 34°55' | 119°35' |
| Cuyamaca Lake | 33°00' | 116°34' |
| Cuyamaca Peak, Cuyamaca Mountains | 32°57' | 116°36.5' |
| Cypress Camp | 40°45' | 121°36.5' |
| Danish Creek | 36°22.5' | 121°42' |
| Dark Canyon | 33°48' | 116°44' |
| Darling Ravine | 40°24.5' | 121°47' |
| Deep Lake | 41°34.0' | 123°06.5' |
| Deer Creek | 35°53.5' | 118°37' |
| Del Monte Forest | 36°35' | 121°56' |
| Democrat Hot Springs | 35°31.5' | 118°40' |
| Descanso | 32°51.5' | 116°37' |
| Devils Canyon | 36°04.5' | 121°35' |
| Devils Gulch | 37°33' | 119°48' |
| Dinsmores | 40°29.5' | 123°36' |
| Division Creek | 36°56' | 118°19' |
| Donomore Meadows | 42°00' | 122°54.5' |

Geographic Location of Place Names, *continued*

| *Name* | *Latitude (N)* | *Longitude (W)* |
|---|---|---|
| Drake Ridge | 35°23.5' | 119°51' |
| Duck Lake Creek | 41°19' | 122°56' |
| Dunnigan | 38°53' | 121°58' |
| Eagle Rest Peak | 34°54.5' | 119°08' |
| East Fork, Ashland Creek (Ore.) | 42°08' | 122°42' |
| East Fork, Elk Creek | 41°43' | 123°18' |
| East Fork, Trinity River | 41°05' | 122°35' |
| East Weaver Lake | 40°49' | 122°59' |
| Eden Valley | 39°37' | 123°10' |
| Elk Hole | 41°36.5' | 123°42.5' |
| Etiwanda | 34°07.5' | 117°31.5' |
| Fish Creek | 34°08.5' | 116°47' |
| Fort Jones | 41°36.5' | 122°50.5' |
| Fort Ross | 38°31' | 123°14.5' |
| Frazier Mt. | 34°46.5' | 118°58' |
| Freeman Creek | 36°08.5' | 118°31' |
| Fremonts (Gabilan) Peak | 36°45.5' | 121°30' |
| Galena Creek (Nev.) | 39°20' | 119°53.5' |
| Galloway Creek | 38°52.5' | 123°39' |
| Garden Valley | 38°51' | 120°51.5' |
| Garfield Grove | 36°20' | 118°43' |
| Garner Valley | 33°39' | 116°39' |
| Genoa (Nev.) | 39°00' | 119°51' |
| Gibson Creek | 36°30.5' | 121°55' |
| Glenbrook (Nev.) | 39°05.5' | 119°56.5' |
| Glenwood | 37°06.5' | 121°59' |
| Gold Hill (Ore.) | 42°26' | 123°03' |
| Goosenest Mt. | 41°43' | 122°13' |
| Gordon Valley | 38°22' | 122°08' |
| Grouse Creek | 40°43' | 123°38' |
| Guadalupe Island (Mexico) | 29°05' | 118°20' |
| Gualala River | 38°46.5' | 123°30' |
| Guatay, Guatay Campground | 32°51.5' | 116°34' |
| Hackamore | 41°33' | 121°07' |
| Haiwee Creek | 36°08' | 118°03' |
| Happy Camp | 41°47.5' | 123°22.5' |
| Hat Creek Rim | 40°45' | 121°24.5' |
| Hawkins Bar | 40°52' | 123°31' |
| Hetch Hetchy Reservoir | 37°57' | 119°44' |
| High Lake | 41°18' | 122°57.5' |
| Hippo Butte | 41°43' | 121°32' |
| Hobart Mills | 39°24' | 120°11' |
| Hooker Canyon | 38°21.5' | 122°28' |
| Hopland | 38°58.5' | 123°07' |
| Horse Meadow | 35°54' | 118°22.5' |
| Horse Range Creek | 41°20' | 122°56.5' |
| Hot Springs Mt. | 33°18.5' | 116°34' |
| Hot Springs Valley[1] | – | – |
| Howell Mt. | 38°34.5' | 122°25.5' |
| Indian Creek | 41°53' | 123°26' |
| Ink Grade | 38°36.5' | 122°27.5' |
| Inskip Butte | 40°20.5' | 121°56.5' |
| Iron Mt. (Ore.) | 42°40.5' | 124°09' |
| Island Butte | 41°41.5' | 121°35.5' |
| Island Mt. | 40°02' | 123°29.5' |
| Jail Canyon | 36°11.5' | 117°07' |
| Jalama Creek | 34°31' | 120°29' |
| Jeffrey Mine Canyon | 37°37' | 118°19' |
| Jess Valley | 41°14' | 120°19' |
| Joe Creek | 41°59' | 123°07' |
| Joshua Tree National Monument | 34°00' | 116°15' |
| Julian | 33°04.5' | 116°36' |
| Junipero Serra Peak | 36°08.5' | 121°25' |
| Kaweah River | 36°26' | 118°55' |
| Kern Plateau | 36°00' | 118°15' |
| Kinevan Canyon | 34°30.5' | 119°49' |
| Kings Range | 40°09' | 124°07' |
| Kingston Range | 35°44' | 115°55' |
| Klamath Mountains[2] | – | – |
| Knopti Creek | 41°56' | 123°41' |
| Labrea Creek | 34°52' | 120°10' |
| Laguna Mts. | 32°52' | 116°25' |
| Lakehead | 40°54.5' | 122°23' |
| Lassen Peak | 40°29' | 121°30' |
| Las Tablas Creek | 35°38.5' | 120°55' |
| Last Chance Creek | 40°07' | 120°25' |
| Last Chance Mts. | 37°17' | 117°42' |
| Latour State Forest | 40°37' | 121°42' |
| Laurel Creek | 37°37' | 118°55' |
| Lava Beds National Monument | 41°45' | 121°30' |

[1]Hot Springs Valley, listed by Sargent (1891) and Jepson (1910) as the southern limit of *Acer macrophyllum*, has not been located on maps of San Diego County. It probably designates the valley southwest of Hot Springs Mountain in which Warner Springs is located.

[2]The term "Klamath Mountains" is used in the context of the "Klamath Mountains geologic province" of northwestern California and southwestern Oregon (Bailey 1966). This 11,800-square-mile region of metamorphic rocks lies between the geologically younger sedimentary Coast Ranges and the volcanic Cascades. A major subdivision of the Klamath Mountains is the Siskiyou Mountains of California and adjacent Oregon. Other components include the Marble, Salmon, Scott, and Scott Bar Mountains, South Fork Mountain, and the Trinity Alps. The southern tip of the Klamath Mountains is near North Yolla Bolly.

Geographic Location of Place Names, *continued*

| *Name* | *Latitude (N)* | *Longitude (W)* |
|---|---|---|
| Laytonville | 39°41' | 123°29' |
| Liebre Mts. | 34°44' | 118°40' |
| Limekiln Creek | 36°01.5' | 121°30.5' |
| Little Salmon Creek | 39°13' | 123°45' |
| Little San Bernardino Mts. | 33°55' | 116°15' |
| Little Stony Creek | 39°17' | 122°35' |
| Little Sur River | 36°20' | 121°52' |
| Lockwood Creek | 36°49' | 118°51.5' |
| Loma Mar | 37°16.5' | 122°18.5' |
| Lone Pine Creek | 36°35.5' | 118°09' |
| Long Meadow | 35°49.5' | 118°20.5' |
| Long Meadow Creek | 35°59.5' | 118°34' |
| Lopez Canyon | 35°15' | 120°30' |
| Loyalton | 39°40.5' | 120°14.5' |
| Luffenholz Creek | 41°02.5' | 124°07' |
| Magalia | 39°48.5' | 121°35' |
| Magee Peak | 40°41.5' | 121°37' |
| Madeline Plains | 40°50' | 120°20' |
| Manchester | 38°58' | 123°41' |
| Marble Mts. | 41°35' | 123°13' |
| Mariposa Grove | 37°30.5' | 119°36' |
| Martin Road | 37°03' | 122°08' |
| Mattole River | 40°15' | 124°10' |
| McArthur-Burney Falls State Park | 41°01' | 121°39' |
| McKinley Grove | 37°01.5' | 119°06' |
| Merced Grove | 37°45' | 119°50' |
| Middle Fork, American River | 39°02' | 120°33' |
| Miller Gulch | 38°35' | 123°18.5' |
| Miller Lake (Ore.) | 42°04' | 123°18' |
| Mineral King | 36°27' | 118°36' |
| Miranda | 40°14' | 123°49.5' |
| Mission San Antonio | 36°01' | 121°15' |
| Mission San Juan Batista | 36°50.5' | 121°32' |
| Mitchell Canyon | 37°54.5' | 121°57' |
| Moffett Creek | 41°38' | 122°45' |
| Monterey Peninsula | 36°36' | 121°56' |
| Montgomery Creek | 40°50.5' | 121°55' |
| Mountain Lakes Wilderness Area (Ore.) | 42°20' | 122°06' |
| Mt. Ashland (Ore.) | 42°05' | 122°43' |
| Mt. Carmel | 36°23' | 121°47' |
| Mt. Diablo | 37°53' | 121°55' |
| Mt. Eddy | 41°19' | 122°28.5' |
| Mt. Fillmore | 39°44' | 120°51' |
| Mt. Hamilton, Mt. Hamilton Range | 37°20.5' | 121°38.5' |
| Mt. Pinos | 34°49' | 119°08.5' |
| Mt. Pleasant | 39°57.5' | 121°10' |
| Mt. Rose (Nev.) | 39°21' | 119°55' |
| Mt. St. Helena | 38°40' | 122°38' |
| Mt. Tamalpais | 37°55.5' | 122°35' |
| Mt. Whitney | 36°34.5' | 118°17.5' |
| Mud Lake | 40°10.5' | 120°43' |
| Music Creek | 41°19.5' | 123°00' |
| Napa Valley | 38°20' | 122°20' |
| Natoma | 38°39' | 121°11' |
| Nelder Grove | 37°26.5' | 119°35' |
| New Idria | 36°25' | 120°40.5' |
| North Butte (Sutter Buttes) | 39°14' | 121°47' |
| North Calaveras Grove | 38°17' | 120°18.5' |
| North Fork, Battle Creek | 40°25' | 121°56' |
| North Fork, Little Sur River | 36°20' | 121°48' |
| North Fork of South Fork, Cow Creek (now called Atkins Creek) | 40°39' | 121°46' |
| North Fork of Middle Fork, Willamette River (Ore.) | 43°53' | 122°15' |
| North Trinity Mt. | 41°06.5' | 123°29' |
| North Yolla Bolly | 40°11.5' | 122°58.5' |
| Nortonville | 37°57.5' | 121°53' |
| Oak Creek | 36°50' | 118°15' |
| Oasis Spring | 32°54' | 116°27.5' |
| Olancha Creek | 36°16' | 118°04' |
| Oregon Caves (Ore.) | 42°06' | 123°24' |
| Owens Peak (Mt. Owen) | 35°44.5' | 118°00' |
| Pacheco Pass | 37°04' | 121°12.5' |
| Palomar Mt. | 33°21.5' | 116°52' |
| Panther Flat Campground | 41°50.5' | 123°56' |
| Peavine Peak (Nev.) | 39°35.5' | 119°56' |
| Phelan | 34°25.5' | 117°34.5' |
| Pigeon Pass | 33°59.5' | 117°16.5' |
| Pilgrim Creek | 41°23' | 122°05' |
| Pilitas Creek | 35°21' | 120°30' |
| Pilot Ridge | 37°46' | 119°56' |
| Pine Meadows | 33°36' | 116°36.5' |
| Pinto Lake | 36°57' | 121°46' |
| Piru Creek | 34°30' | 118°45' |
| Pit River Power House No. 1 | 40°59.5' | 121°30' |
| Piute Mts., Piute Peak | 35°27' | 118°23.5' |
| Placer Grove | 39°03.5' | 120°34' |
| Plantation | 38°35.5' | 123°18.5' |

Geographic Location of Place Names, *continued*

| *Name* | *Latitude (N)* | *Longitude (W)* |
|---|---|---|
| Pleasants Peak | 33°48' | 117°36.5' |
| Point Arena | 38°57' | 123°44.5' |
| Point Pinos | 36°38' | 121°56' |
| Potrero Creek | 32°36' | 116°39' |
| Preston Peak | 41°50' | 123°36.5' |
| Prospect (Ore.) | 42°45' | 122°29' |
| Pulga | 39°48' | 121°27' |
| Purisima Hills | 34°44' | 120°20' |
| Rancheria Creek | 37°57' | 119°41' |
| Reading Creek | 40°36.5' | 122°55' |
| Red Mt. | 39°57' | 123°40.5' |
| Redwood Creek | 41°05' | 123°52' |
| River Pines | 38°33' | 120°44.5' |
| Rogue River (Ore.) | 42°28' | 123°30' |
| Roseman Creek | 38°49.5' | 123°36' |
| Round Mt. | 40°48.5' | 121°57.5' |
| Russ Gardens (6th and Harrison Sts., San Francisco) | 37°46.5' | 122°24' |
| Russian Gulch | 39°20' | 123°48' |
| Russian Peak | 41°17' | 122°57' |
| Salmon Creek | 35°49' | 121°21.5' |
| Salmon Mts. | 41°10' | 123°22' |
| Salton Sea | 33°15' | 115°45' |
| Salyer | 40°53.5' | 123°35' |
| San Antonio Canyon | 36°02.5' | 121°28' |
| San Benito Mt. | 36°22' | 120°38.5' |
| San Carlos (Diablo) Range | 36°20' | 120°45' |
| San Carpoforo Creek | 35°47' | 121°16.5' |
| San Dimas | 34°06.5' | 117°48.5' |
| San Emigdio Canyon | 34°55' | 119°10' |
| San Emigdio Range | 34°52' | 119°10' |
| San Felipe | 33°12' | 116°36' |
| San Felipe Canyon[3] | - | - |
| San Fernando Valley | 34°13' | 118°30' |
| Sanger Lake | 41°54' | 123°39' |
| San Lorenzo River | 37°05' | 122°05' |
| Santa Rosa Mts. | 33°31' | 116°25' |
| Santa Ynez Valley | 34°37' | 120°05' |
| Santiago Peak | 33°42.5' | 117°32' |
| San Vicente (Mexico) | 31°20' | 116°21' |
| San Ysidro Mts. | 32°35' | 116°50' |
| Sawtooth Peak | 35°49.5' | 118°00' |
| Scott Bar Mts. | 41°42' | 122°55' |
| Scott Camp Creek | 41°15' | 122°23.5' |
| Scott Mts. | 41°17' | 122°41' |
| Scott Valley | 41°30' | 122°52' |
| Seiad Creek | 41°52.5' | 123°08' |
| Sentenac (San Felipe) Canyon | 33°06.5' | 116°27' |
| Shastina | 41°24.5' | 122°13.5' |
| Shotgun Creek | 41°03.5' | 122°23' |
| Sierra Peak | 33°51' | 117°39' |
| Sierra Valley | 39°45' | 120°20' |
| Silliman Lake | 36°38' | 118°42' |
| Sirretta Peak | 35°55.5' | 118°20' |
| Skinner Ridge | 36°22' | 121°48' |
| Slick Rock Creek | 38°50.5' | 123°37' |
| Snow Mt. | 39°22.5' | 122°45.5' |
| Soldier Ridge | 40°01.5' | 122°58.5' |
| Somersville | 37°57.5' | 121°52' |
| South Calaveras Grove | 38°15' | 120°14' |
| South Fork, Kaweah River | 36°22' | 118°50' |
| South Fork, Kern River | 36°00' | 118°08' |
| South Fork, Kings River | 36°48.5' | 118°45' |
| South Fork Mt. | 40°30' | 123°30' |
| South Fork, Salmon River | 41°08.5' | 123°10' |
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| South Yolla Bolly | 40°02' | 122°51' |
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| Sugar Creek | 41°18' | 122°55' |
| Sugar Hill | 41°48.5' | 120°19.5' |
| Sugar Lake | 41°18' | 122°56.5' |
| Sunday Peak | 35°47' | 118°35' |
| Sutter Buttes | 39°13' | 121°49' |
| Swanton | 37°04' | 122°13.5' |
| Swartz Creek | 38°38.5' | 122°29' |
| Sweetwater Mts. | 38°25' | 119°18' |
| Telescope Peak | 36°10' | 117°05.5' |
| Temblor Range | 35°15' | 119°45' |
| Ten Mile Valley | 39°44.5' | 123°31' |
| The Cedars | 38°38' | 123°07' |
| Thing Valley | 32°48' | 116°23' |

[3]San Felipe Canyon cannot be located on current maps of northeastern San Diego County, although it is still cited as one of the southernmost outliers of *Pseudotsuga macrocarpa* (Bolton and Vogl 1969). Jepson (1910) probably referred to Banner Canyon when he placed San Felipe Canyon between Banner and Julian. In the past Sentenac Canyon, 6-7 miles northeast of Banner, has sometimes been called San Felipe Canyon, but this locality is improbably low and arid for *Pseudotsuga macrocarpa*. The "San Felipe Canyon" locality of this species is most likely based on the type collection from the mountains near San Felipe, 8-9 miles north of Banner and Julian. *Pseudotsuga macrocarpa* still grew less than a mile from San Felipe at the time of the VTM survey.

Geographic Location of Place Names, *continued*

| *Name* | *Latitude (N)* | *Longitude (W)* |
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| Timbered Crater | 41°10' | 121°29.5' |
| Topatopa Mts. | 34°32' | 119°02' |
| Toro Creek | 36°35' | 121°43' |
| Trinidad Head | 41°03.5' | 124°09' |
| Trinity Alps | 41°00' | 123°00' |
| Tule River | 36°06' | 118°50' |
| Tuolumne Grove | 37°46' | 119°48.5' |
| Umpqua River (Ore.) | 43°30' | 123°30' |
| Van Duzen River | 40°32' | 123°45' |
| Ventana Camp | 36°15.5' | 121°44.5' |
| Verdi (Nev.) | 39°31' | 119°59.5' |
| Virgin Creek | 39°28' | 123°47' |
| Virginia Range (Nev.) | 39°20' | 119°40' |
| Walker Ridge | 39°05' | 122°29' |
| Walnut Creek | 37°55' | 122°03' |
| Warner Springs | 33°17' | 116°38' |
| Weitchpec | 41°11' | 123°42.5' |
| Wheeler Peak | 40°06.5' | 120°41' |
| Whiskey Peak (Ore.) | 42°01.5' | 123°15.5' |
| Whiskeytown Lake | 40°38' | 122°34' |
| Willow Creek (Monterey Co.) | 35°53.5' | 121°27' |
| Willow Creek (Sonoma Co.) | 38°26' | 123°05' |
| Wyman Creek | 37°26' | 118°05' |
| Yreka Creek | 41°45' | 122°37.5' |
| Zaca Lake | 34°46.5' | 120°02.5' |
| Zaca Peak | 34°46' | 120°01.5' |

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The distribution of 86 forest and woodland tree taxa native to California is illustrated on maps. Descriptive notes relate the distribution of each species to its ecological and taxonomic context, including the plant communities in which the tree commonly appears. Nearly one-fourth of the species illustrated are restricted to California, and the distribution of many others is centered in the State.

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# LOGGING SLASH:

## its breakdown and decay at two forests in northern California

Willis W. Wagener Harold R. Offord

USDA FOREST SERVICE RESEARCH PAPER PSW-83 1972

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## The Authors

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The economic disposal of logging slash has long been a problem in fire protection and stand improvement. As Woodbury, Burnett, and Edmonds (1935) point out the problem is particularly acute under critical fire conditions that prevail in California. Decisions about what to do with slash are based in part on information on its rate of breakdown and decay. Slash changes in structure and volume from a complicated interplay of physical and enzymatic agents and the physical and biological characteristics of tree species. Rate of breakdown and decay, therefore, varies widely in major forest types. Rates have been reported for species in the Pacific Northwest (Childs 1939), South (Long 1917; Toole 1965), Northeast (Spaulding 1929; Spaulding and Hansbrough 1944), Midwest (Zon and Cunningham 1931), and Southwest (Gill and Andrews 1956). Kimmey (1955) reported studies of the rate of deterioration of fire-killed timber in California.

In California, a study of unburned logging slash was started in 1923 and concluded in 1957. Over this 34-year period, discrete piles of slash and marked strips of lopped and scattered slash were periodically observed and measured. The influences having the greatest impact on compaction, checking, and decay were assessed. These influences are climatic (precipitation, temperature, insolation, soil moisture) and biologic (characteristics of tree species and decay fungi). Such relatively minor agents of physical breakdown as insects and animals are not quantitatively evaluated in this study.

This paper reports data on slash breakdown and decay for four conifer species under conditions typical at two sites on the Sierra Nevada, northern California, and suggests their implications for forest protection and management. The findings provide a basis for interpreting the records of slash studies in other regions.

## EXPERIMENTAL AREAS

Forest pathologists[1] began their studies in Cow Creek drainage, Stanislaus National Forest, in 1923, and near Antelope and Logan Mountains, Lassen National Forest, in 1927.

The Stanislaus plots were on gently sloping ground with a general northwest exposure in Cow Creek, a westward flowing tributary of the Middle Fork of the Stanislaus River. Elevations ranged from 5,300 to 5,700 feet. The soil, with occasional granite outcrops, was a friable loam of granitic origin. On plot sites it averaged 4 feet or more in depth.

A virgin, uneven-aged, mixed-conifer stand averaging 43,000 to 50,000 board feet per acre were present before logging. The area averaged a high Site II, and portions were Site I. The stand consisted of sugar pine *(Pinus lambertiana* Dougl.)—39 percent, by merchantable volume; ponderosa pine *(Pinus ponderosa* Laws.)—24 percent; white fir *(Abies concolor* [Gord. and Glend.] Lindl.) —27 percent; and incense -cedar *(Libocedrus decurrens* Torr.)—10 percent. The litter and duff layer was about 1 to 2 inches deep. Logging was by steam donkey with ground leads.

The stand generally was sound. Many of the older trees were fire-scarred at the base, but the wounds were small, and the butt rot from decay fungi was not extensive. Heart rot from the Indian paint fungus *(Echinodontium tinctorium* Ell. and Ev.) caused occasional cull in white fir trunks, and many of the older incense-cedars were cull because of decay by the pocket dry rot fungus *(Polyporus amarus* Hedgc.). Dead and broken tops were fairly common in white fir from the combined action of the true mistletoe *(Phoradendron bolleanum* ssp. *pauciflorum* [Torr.]) and beetles.

One plot on the Lassen was on the lower eastern slope of Antelope Mountain at 6,000 feet elevation. The remaining 152 plots and sample strips were on moderate southeastern and southwestern slopes of nearby Logan Mountain at elevation ranging from

[1]Studies were started under the general direction of E. P. Meinecke, pathologist in charge. After 1928 they were the responsibility of Willis W. Wagener. Lake S. Gill, Ernest Wright, and James W. Kimmey took major parts in field work. Others who aided in field work were H. N. Hansen, L. W. Musick, James L. Mielke, and Paul C. Lightle.

6,300 to 6,600 feet. The soil is mostly derived from basalts. On the Logan Mountain sites, weathered broken andesite blocks extended to the soil surface with soil pockets interspersed. Soils were relatively fine-grained. On the Antelope Mountain plot, soils were deeper, and basalts were not ordinarily exposed.

The virgin timber stands occupying the areas before logging consisted primarily of ponderosa pine, Jeffrey pine *(Pinus jeffreyi* Grev. and Balf.*)*, and white fir, with small admixtures of sugar pine and incense-cedar. Stands were relatively open, averaging slightly more than 22,000 board feet per acre, of which an average of 16,600 board feet were removed in logging. Surface litter and duff were thin, varying from negligible to 1 inch in depth. Site classification varied between a low III and a high IV.

The amount of cull in pine was low on the study area, and few cull logs remained after logging. White fir was much more defective—partly from frost cracks and partly from heart rot of the trunk from the Indian paint fungus. Stem and butt rots, such as *Pholiota adiposa* (Fr.) Quel., and *Polyporus schweinitzii* Fr., were also fairly common. Cull green trees and dead snags, which were felled and left to lie in place, averaged 3.5 per acre. Logging was by crawler tractor.

## FIELD PROCEDURES

In both study areas, plots were checked yearly for the first 5 years and then at widening intervals until final checks in 1957. Data were recorded on discrete piles of slash, lopped and scattered slash, and larger wood chunks or logs variously situated on flat or sloping ground of differing aspect. Representative plots were photographed. In the two areas, 324 piles or strips (171 on the Stanislaus and 153 on the Lassen) were established, mapped, and checked. On the Stanislaus, emphasis was on piled slash, and slopes were northwest and northeast. On the Lassen, emphasis was on scattered slash as left after tractor loggings on east, northeast and southwest slopes.

Old dry branches dead before logging were omitted from piles of green slash. Pile composition depended on slash available, but wherever practicable single species piles were erected. On the Stanislaus, 23 percent of the piles were of two or more tree species. On the Lassen, 20 percent of piles had two or more species in the same pile. Of the single species piles 53 percent was ponderosa pine (no attempt was made to distinguish between ponderosa pine and Jeffrey pine); 25 percent, white fir; 15 percent, sugar pine; and 7 percent, incense-cedar.

Experience on the Stanislaus in the first years of the study showed that most piles erected with a loose structure (some of the piles had been formed as compactly as possible) showed little subsidence. On the Lassen, therefore, no attempt was made to achieve a loose pile.

During the early years of the study, physical characteristics of litter and soil, amount of shade and soil moisture, retention or deterioration of foliage and bark, and general condition of sapwood and heartwood were recorded. Later records included the appearance of stain, progress of decay, the nature of the decay fungi, and presence of insects. Except for height measurements of slash piles that were made by yardstick, quantitative data are based on recorded ocular estimates.

Weather records for most of the study period (30 years) were available from the Stanislaus-Tuolumne and Blacks Mountain Experimental Forests. These two Experimental Forests are close enough to the two study areas to provide a reliable basis for evaluating the influence of local weather on slash decay.

## PROGRESS OF SLASH BREAKDOWN

### *Weather Influences*

Soil and air moisture and temperature and the characteristics of tree species largely determine how rapidly slash breaks down once the live material has been piled or scattered. Enzymatic organisms that contribute to decay deterioration of slash are omnipresent. High summer temperatures in the absence of rain have long been known to have a limiting if not lethal effect on mycelium of wood-destroying fungi (Loman 1965).

Mean seasonal precipitation at the Stanislaus-Tuolumne Experimental Forest for an 18-year period

(1936-1954) was 38 inches, but only 18.14 inches at Blacks Mountain for that period. *(fig. 1).* Summer dryness is more continuous at Stanislaus-Tuolumne because summer thunderstorms are infrequent. During 19 summers, beginning in 1936, precipitation was under 0.25-inch total for 3 consecutive months in 10 of 19 summers at Stanislaus-Tuolumne and in none at Blacks Mountain.

Snow, which strongly affects compacting of slash, constitutes more than half of the total precipitation at Stanislaus-Tuolumne. Maximum depths seldom exceed 7 feet on cutover areas. In most years snow covers the ground for about 4-1/2 months at an average depth of about 2 feet.

At Blacks Mountain, about half of the total precipitation is snow, and maximum depths seldom exceed 3 feet. For the 3-1/2 months when snow ordinarily persists, it averages about 1 foot deep. Water content of the snowpack runs about 40 percent in both the Lassen and Stanislaus areas.

Summer humidities average low at both locations. Mean moisture for July and August combined, as determined from calibrated moisture sticks, varied from 5 percent in 1959 to 9.4 percent in 1958 near the Stanislaus plots, and from 5 to 7.7 percent between 1956 and 1959 at Bogard Ranger Station, near the Lassen plots. These amounts are all well below the approximate 20 percent moisture content limit at which most decay fungi become inactive.

Mean monthly maximum and minimum temperatures tend to be somewhat higher at Stanislaus-Tuolumne than at Blacks Mountain except in July, when the mean maximum at Blacks Mountain rises slightly above that at Stanislaus-Tuolumne *(fig. 2).* Mean minimum temperatures are above freezing for about 155 days at Stanislaus -Tuolumne and 125 days at Blacks Mountain.

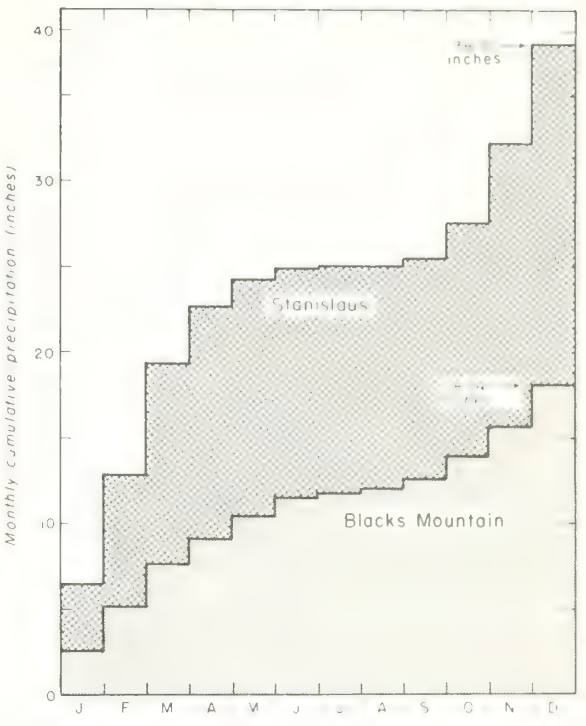


**Figure 1**—Cumulative mean annual precipitation, by months, from July 1936 to June 1954 at the Stanislaus-Tuolumne and Blacks Mountain Experimental Forests, California.

## Processes of Breakdown

The impact of climatic and biologic influences may be traced through observations on compaction, checking, and decay in the piled and scattered slash on the study locations.

### Compaction

Compaction was particularly noticeable in slash aggregated in piles or windrows. In the study areas, about 50 percent of the reduction in pile height occurred in the first 5 years after logging *(fig. 3).* Most of the initial subsidence is attributable to the weight of slash itself plus the compressing action of snow.

On both areas, after the first 2 years, the breaking up of twig and branch wood from cross-checking gradually assumed importance. Eventually, in combination with decay fungi, it predominated as the cause of pile height reduction. Slash piles at Stanislaus decreased more quickly in height than those at Lassen for a period of about 15 years *(fig. 3).* Over extended periods, however, the subsidence occurred at rates generally characteristic of a single species pile, such as ponderosa pine *(fig. 4)* and white fir *(fig. 5).* Over a period of 29 years the ponderosa pile *(fig. 4)* subsided from an initial height of 5 feet to 1.5 feet—a 70 percent drop; the white fir pile *(fig. 5)* subsided from 4.8 feet to 0.6 foot—an 87 percent drop. Subsidence of white fir was especially rapid, by comparison with pine during the first 16 years.

In scattered slash no easily replicable measurements of height could be made as a basis for comparison. Apparently, initial subsidence in scattered slash depends much more on breakup from checking alone than on the combined influences of slash weight, snow, and checking which operate on piled slash. The impact of animals is greater on scattered than on piled slash.

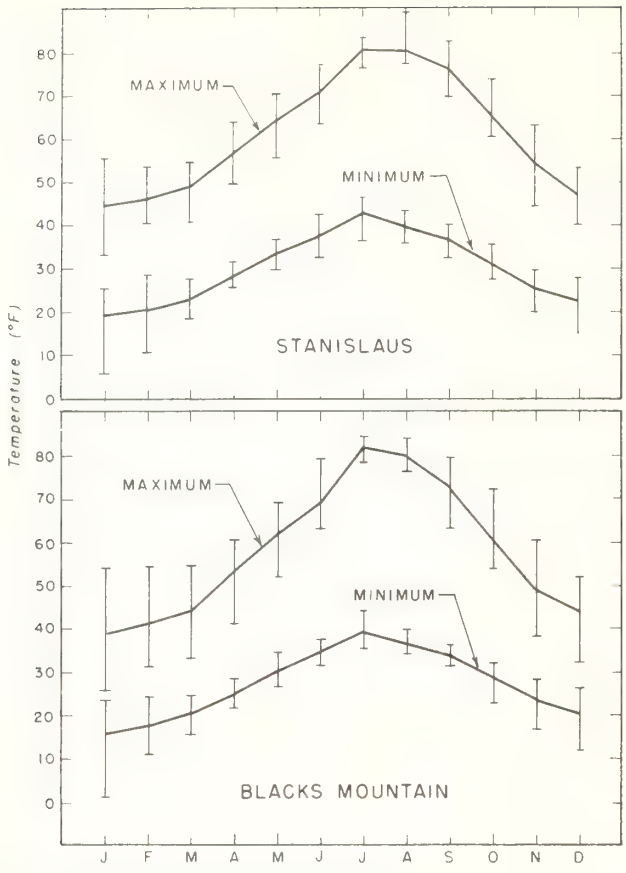


**Figure 2**—Mean monthly maximum and minimum temperatures and range of deviations at weather station No. 4, Stanislaus-Tuolumne and Blacks Mountain Experimental Forests, California, from 1937 to 1953.

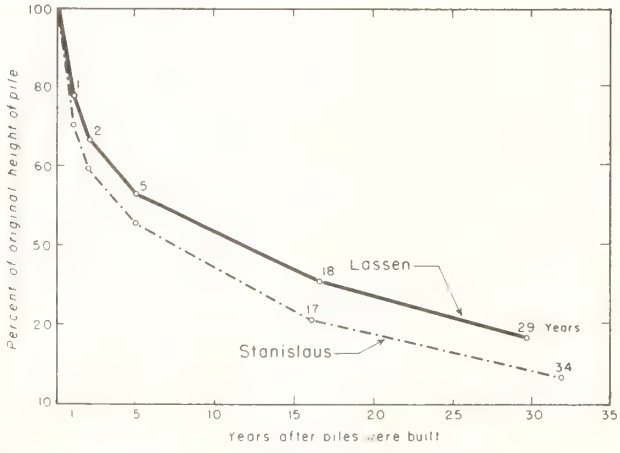


**Figure 3**—Comparative subsidence in mean height of 83 slash piles on the Lassen National Forest during 29 years, and of 123 piles on the Stanislaus National Forest during 34 years. Data are from all usable piles of single and mixed tree species.

**Figure 4**—Subsidence of piled ponderosa and Jeffrey pine slash on Plot No. 2, Lassen National Forest, during a 29-year period: **A**, As piled the year of logging (1928), height 5 feet; **B**, 2 years later (1930), height 3.5 feet; **C**, 16 years later (1944), height 2.5 feet; **D**, 29 years later (1957), height 1.5 feet.

Changes occurring over a 29-year period in scattered logging slash, mostly ponderosa pine, on one of the Lassen study strips on Logan Mountain are seen in *figure 6.* By 1957 estimated wood volume, including the larger chunks, had been reduced to about one-third or less of the original volume.

## Checking

Shrinkage in twigs and branches from the high temperature and low humidity of summer results in checking. It causes twig and branch wood to break into shorter lengths—notably in slash exposed to full sunlight *(fig. 7).* Checking is most pronounced in the compression wood at the base of branches—especially in white fir wood. Of the species in these studies, incense-cedar was least affected and white fir the most affected. Breakup from checking appeared to be dominant in the reduction of slash from about the third to the eighth year after logging. In general checking was least rapid on north slopes.

On the Stanislaus plots, 4 years after piling, most twigs and small branches had broken off from main branches. This condition was less marked under shelter of trees or where slash was piled deeply.

Three years after piling, in the Lassen area, white fir showed about 20 percent breakup of small limbs from cross checks. By the sixth and seventh year, nearly all twigs and limbs had broken away from the main stem, leaving scattered limb stubs. Remnants of limbs were most noticeable on pine and incense-cedar.

Checking occurs in bark as well as in wood. Partial loosening of the bark from the wood usually accompanies checking and was noticeable a year after deposition of slash, becoming widespread by the fifth year.

**Figure 5**—Subsidence of piled white fir slash on strip No. 4, Lassen National Forest, during a 29-year period: **A**, As piled the year of logging (1928), height 4.8 feet; **B**, 2 years later (1930), height 3.5 feet; **C**, 16 years later (1944), height 1.5 feet; **D**, 29 years later (1957), height 0.6 foot.

**Figure 6**—Changes in scattered logging slash on strip ,No. 4 (Logan Mountain) Lassen National Forest, a gentle southwest slope, during a 29-year period: **A**, Just after logging in 1928; **B**, 4 years later (1932). Foliage had dropped and there was considerable checking in smaller branches; **C**, 16 years later (1944). Decay from *Fomes pinicola* (Fr.) Cke. and *Lentinus lepideus* Fr. has become significant; **D**, 29 years later (1957). Volume is approximately one-third of original.

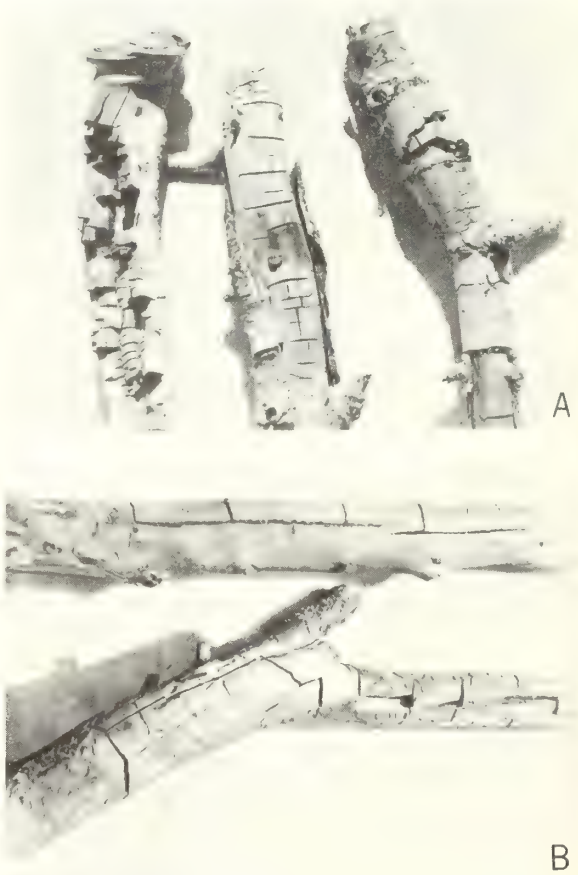


**Figure 7**—Checking of small branch wood takes place both with and across grain and is usually most pronounced in full sun and in compression wood at the base of branches. It is illustrated in **A**, white fir 6 years after logging; and **B**, sugar pine 7 years after logging.

Within a period of 2 to 4 years after piling of slash, cts accelerate the loosening of bark on both small ches and larger limbs and logs. By tunnels and ngs in chunks, tops, and logs they contribute to breakup of solid wood that takes place over er periods of time.

n 1930, Willis W. Wagener identified six stages of breakdown –all of some significance to fire rol and other protection and management prob-s–from ocular estimates made from 46 plots of l slash on the Stanislaus (Woodbury, Burnett, and ionds 1935). These estimates for the six stages of kdown for ponderosa pine, sugar pine, white fir, incense-cedar are summarized in *figure 8.*

## ay

freezing temperatures in winter, and scarcity of in summer and early fall, greatly restrict the vity of wood-rotting fungi in logging slash. Branch d is usually too dry to permit fungus action ept for limited periods in spring and fall. This dition exists in all but large pieces having bark k enough to retain considerable moisture in the d. Oleoresins in the bark and wood of twigs and ches of conifers probably further inhibit estab-ment of decay fungi during the first few years r logging. In the branch wood it is only after 7 to 10 years that fungus action contributes significantly to slash deterioration. Initial major effects of decay fungi were visible after some 15 years, when compaction and breakup from checking had reached peaks and were then diminishing *(figs. 4, 5, 6).*

Other influences on the starting time and progress of decay include the higher minimum temperatures on the Stanislaus *(fig. 2A, 2B)* and the correspondingly longer period when minimum temperatures are above freezing–155 days on the Stanislaus against 125 days on the Lassen. Partly compensating for this difference is greater frequency of summer showers on the Lassen than on the Stanislaus.

The degree to which needles are in contact with the soil influences the start of their decay. By the second year after piling, most of the foliage of white fir had dropped while incense-cedar and ponderosa pine still retained up to 40 percent. This retained foliage tended to be on branches that were bent down, shaded, and close to the ground. Three to 4 years after piling, all needles had fallen from exposed slash; needles on the ground were well matted and partly decayed. Under trees or in the semiprotection of brush a few sugar pine or ponderosa pine needles were still attached to branches even after 4 to 5 years. Rocky soil on the Lassen generally allowed less contact with the soil, thus minimizing the rapid establishment and action of needle-decaying fungi.

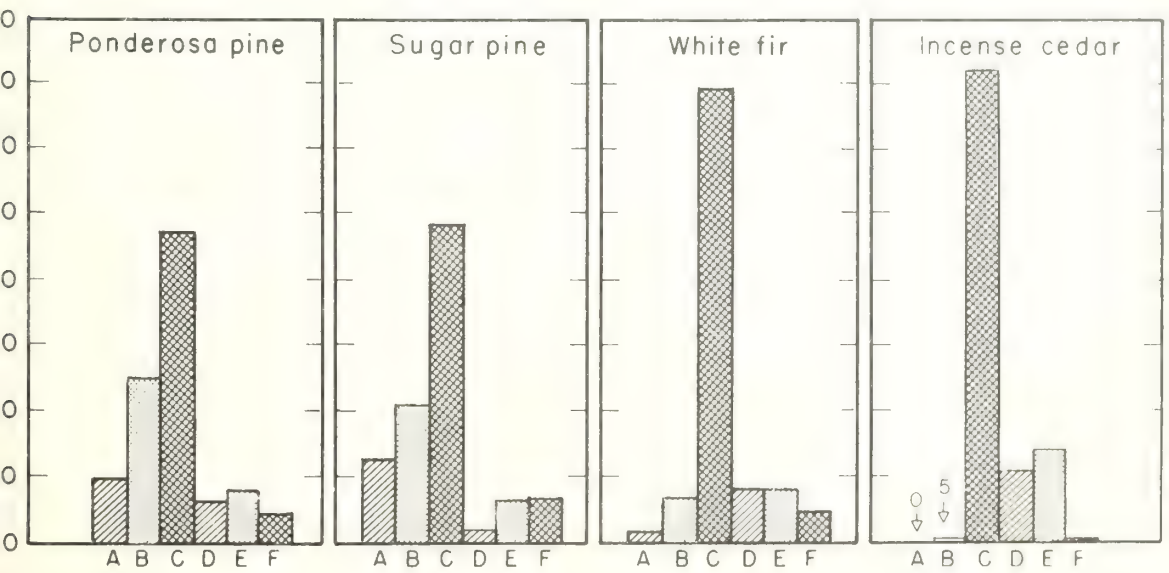


**Figure 8**–Stages of slash breakdown in four tree species at end of 7 years in 46 plots, Stanislaus National Forest. Key: **A**, bark tight in place; **B**, bark loose and in-place limbs slightly checked; **C**, bark loose and partly sloughed; limbs slightly checked; **D**, bark entirely sloughed, medium checking on all limbs; **E**, bark entirely sloughed, heavy checking; **F**, limbs broken into small cubical sections, some evidence of decay.

## Principal Decay Fungi

Two to 3 years after piling, the only notable decay in woody chunks or large pieces was in material lying on the ground or imbedded in it. At the 5-year-interval, some decay from *Polyporus abietinus* (Fr.) Dicks. had started in white fir tops, chunks, or pieces where the bark was thin or cracked *(table 1)*.

Table 1–*Wood decay fungi identified on slash study plots (piles, chunks, and logs), Stanislaus and Lassen National Forests, California*

| Fungus[1] | Stanislaus | Lassen | Total |
|---|---|---|---|
| | *No. of Plots* | | |
| *Polyporus abietinus* (Fr.) Dicks. | 9 | 15 | 24 |
| *Fomes pinicola* (Fr.) Cke. | 9 | 14 | 23 |
| *Lenzites saepiaria* Fr. | 2 | 10 | 12 |
| *Polyporus volvatus* Pk. | 8 | 3 | 11 |
| *Lentinus lepideus* Fr. | 3 | 1 | 4 |
| *Poria subacida* (Pk.) Sacc. | 2 | 2 | 4 |

[1]Excluded as unimportant to decay of slash are the principal heart-rot fungi commonly found in cull logs or large limb chunks: i.e., *Echinodontium tinctorium* in white fir, *Polyporus amarus* Hedgc. in incense-cedar, and *Fomes pini* Fr. (Karst.) in the pines.

During the first 7-year period, only a few instances of fruiting of decay fungi were noted. Of these *Polyporus abietinus* and *Lenzites saepiaria* Fr. were most active in decay of slash. *Fomes pinicola* (Fr.) Cke. is one of the principal fungi rotting white fir and pine logs or chunks, but it does not ordinarily work in material less than 10 inches in diameter. The cubical brown rot *Lentinus lepideus* Fr. occurred throughout the general area, but was recorded on only three of the Stanislaus plots. Sporophores of the pouch fungus *Polyporus volvatus* Pk., which appeared abundantly on tops and on down logs during the second year, probably accelerated subsequent decay of sapwood by the more aggressive *F. pinicola* and *P. abietinus* (Kimmey 1955). Two agarics *(Pholiota* and *Pleurotus* spp.*)* were often found fruiting on down white fir logs and undoubtedly helped the sapwood to decay.

## Stages of Slash Decay

Observations on the presence and the effects of fungi at various intervals were as follows *(table 2)*:

*Years 1-2*–Duff fungi, mostly of the filamentous type, extends to needles and bark of branches on the ground. No decay is noted in twigs or branches except those partly buried in mineral soil. Incipient decay in logs and larger tops of white fir is noticeable during the second year where bark is still retained. In pine, stain and incipient decay is confined to sa wood. *P. volvatus* becomes established in sapwood.

*Years 3-5*–Foliage in contact with ground decayed to various degrees. Portions of branch buried or in contact with mineral soil are bad rotted, but decay does not extend appreciably abo ground. Rot development in pieces under 10 inches diameter slows markedly when bark loosens and t wood begins to check, as wood becomes too dry support fungus growth during summer.

*Years 6-7*–About half the foliage is disintegrate the remainder being in various stages of decay *(fig. 8*

Table 2–*Typical pattern of decay in log, top, or chunk f the four principal tree species during a 32-year period study plots, Stanislaus National Forest, California*[1]

| Species and type | Stage of decay and years after pilin |
|---|---|
| *Abies concolor*: Top, 10-inches in diameter at large end | Decay 3/4 to 1 inch deep in log fa under dirt |
| | *Fomes pinicola* in sapwood over pa of log |
| | *Polyporus abietinus* in inner bark a wood in part of top |
| | About 6 inches of small end soun rest of piece decayed, starting collapse. *Lenzites saepiaria* on part outer dry shell |
| | Total collapse except small portic of upper sapwood shell |
| *Libocedrus decurrens*: Broken log, 15-inches average diameter | Surface of wood darkened |
| | Slight stain but no decay found |
| | Slight decay in part of sapwood |
| | Sapwood decayed except f case-hardened shell. Heartwood st mostly sound |
| *Pinus ponderosa*: Top, 10-inches in diameter at large end | *Polyporus volvatus* superficial sapwood |
| | Slight amount *P. abietinus* rot sapwood |
| | *F. pinicola* in heartwood and und side of top |
| | Interior general decay (heartwoo and some sapwood decay. *Lentinu lepideus* and *F. pinicola* noted |
| | Piece collapsed and decay gener throughout piece |
| *P. lambertiana*: Broken log chunk | *P. volvatus* superficial to 1/4 inc sapwood |
| | *P. volvatus* and *F. pinicola* heartwood under one side of log |
| | Sapwood mostly decayed; heartwoo about 15 percent decayed |
| | Total collapse except for patches o sapwood and heartwood that retai structure |

[1]Results as recorded at 2-, 12-, 17-, and 30-year intervals fo the same species on the Lassen National Forest ar substantially the same.

siderable foliage in the interior of pure pine piles ill well preserved. In most protected spots, a small unt of decay is found in branches off the ground. s and tops vary widely in condition; controlling ors are tree species, shade, and degree of bark ghing.

*ears 8-16*–Subsidence in small-diameter slash, h made up most of the test piles, during this od is about 16 percent on the Lassen and 18 ent on the Stanislaus. Perhaps half of this ction represents loss of wood volume through y and physical breakdown. In the tops and nks, decay fungi are clearly taking a significant toll of solid wood–especially in white fir *(table 2)*.

*Years 17-32*–Decay is most rapid for white fir and slowest in incense-cedar; the pines were intermediate. Observations of the frequency and effects of the important slash decay fungi during this period highlight the pathological findings of primary concern to forest managers *(tables 1,2)*. Of 308 specimens collected from plots, 186 relate to foliage and superficial bark and 122 to wood of twig, branch or log.[2] Among the genera collected from the slash study plots but not otherwise referred to in this paper are *Pholiota, Poria, Corticium, Merulius, Coniophora, Stereum,* and *Pleurotus.*

# MANAGEMENT IMPLICATIONS

eneral observations of the Stanislaus study area 957–34 years after logging–showed that it ared to be approaching pre-logging conditions, ugh significant residues of the larger pieces of s were still on the ground. Incense-cedar and large g pine limbs had broken up and disappeared the s Decay was most rapid in dense shade but more p in the open than in partial shade. In open areas, eup by checking was an important factor–more n level or nearly level ground than on north gs. Growth of reproduction and consequent shade dncrease in thickness of duff played an important rin slash decay.

Inal observations on the Lassen 29 years after ggig essentially agreed with those on the arslaus, but with some differences. Effects of inls on physical breakup of slash were more pent. And, the occurrence and extent of decay in ni fir by *P. abietinus* and in pine and fir by *F. niola* and *L. saepiaria* were more notable.

C Logan Mountain (Lassen), a sample strip run in 5–29 years after logging–showed that about 43 rcnt of the heavier wood in the original coniferous sh still remained. Lop and scatter plots generally nt ned log chunks and larger limbs than the slash edn constructing the test piles.

Fe control and forest management personnel gh take this 43 percent figure as a rough measure l applied against published slash and litter igts. Chandler (1960) provides estimates of the y eight of slash in pounds per tree and pounds per ound board feet, by species (ponderosa pine, gar pine, Douglas-fir, white fir, and incense-cedar), r rious size classes and crown lengths. Sundahl 96) reported that for the ponderosa-fir type in 90-year-old stands at the Challenge Experimental Forest in northern California, about 44 tons per acre of coniferous slash after logging could be expected. Hardwoods and litter combined to make an additional 53 tons per acre. An over-all average of 85 percent height reduction for all piles on the Lassen and Stanislaus approximated 60 to 70 percent reduction in volume of branchwood.

## *Stability of Slash*

An objective of the California study was to confirm field observations suggesting that slash in the mixed conifer type of the Sierra Nevada was more stable and persistent than slash in other regions. For example, Spaulding and Hansbrough (1944) reported that the time for breakdown and decay of eastern white pine slash averaged 17 years, and that *Lenzites saepiaria* and *Polyporus abietinus* were primary decay fungi responsible.

In pine forests of the southwest *P. anceps* Pk. was the most abundant and active of the decay fungi, causing breakdown of slash in 8 to 15 years. Of the secondary fungi *P. abietinus* required more outside moisture than *L. saepiaria* and was also more restricted by high temperature. Both of the secondary fungi took about twice as long as *P. anceps* to bring about comparable decay (Gill and Andrews 1956).

Pine slash in California, in the virtual absence of *P. anceps* and under generally dry hot summer conditions, remained in substantial amounts after 15 years.

[2]Notes on this collection are on file at the Pacific Southwest Forest and Range Experiment Station, Berkeley, California.

In the Pacific Northwest, about 90 percent of wood volume in unburned Douglas-fir slash decayed some 16 to 20 years after logging (Childs 1939). The comparable figure for burned slash was 78 percent. "Wet rots" caused by *Ganoderma oregonense* Murr. and *Fomes applanatus* (Pers. Wallr.) were abundant on the spruce hemlock slashings in humid areas of western Washington. The importance of moisture in accelerating the decay of slash was emphasized by Childs (1939) who reported that disintegration of needles and twigs on Douglas-fir and on spruce hemlock sites is usually complete after 10 to 12 years. In contrast, some foliage and much of the small twig material may remain at the end of 10 years on very dry sites in Douglas-fir type. This latter situation is similar to that noted in the dry mixed conifer areas of California.

## Fire Hazard Classes

In relating slash deterioration to fire hazard, Spaulding and Hansbrough (1944) identified four classes for softwoods, ranging from *extreme* to *low*. Toole (1965) also proposed four classes for hardwoods. The *extreme* class includes relatively undecomposed slash retaining most of the leaves and small twigs still high in oleoresin; the *low* class represents conditions approaching those before logging when litter was flat on the partially or completely shaded ground. To bring about this change in fire hazard of slash took 17 years for white pine in the Northeast but only 6 years for hardwoods (exclusive of cottonwood) in the South. A similar shift in fire hazard from *extreme* to *low* in mixed conifer Sierra Nevada regions of California would require an estimated 30 years or more. The California study suggests that about one-third of the original volume of wood (exclusive of foliage and small twigs) was still undecayed after a lapse of about 30 years.

Fahnestock and Dieterich (1962) in their studies of flammability of coniferous slash in the northern Rocky Mountain region showed a 56 percent reduction of the original volume of ponderosa pine after 5 years.

The prevalent decay fungi in the California study areas are of the dry, brittle, carbonizing type which induce partially decayed wood having high fire hazard, and not the soft "wet" rots predominant in the Pacific Northwest. Residue of the true firs was notably less durable than that of pine and incense -cedar. On the Sierra Nevada, lopped and scattered slash decays very slowly in all areas exposed to direct sunlight. Compact piles of slash—especially on gentle north and northeast slopes in partial or better shade—decay more rapidly than loosely piled "cordwood" piles in the same or in drier environment.

# SUMMARY


Wagener, Willis W., and Harold R. Offord

1972. **Logging slash: its breakdown and decay at two forests in northern California.** Berkeley, Calif., Pacific SW. Forest & Range Exp. Stn. 11 p., illus. (USDA Forest Serv. Res. Paper PSW-83)

*Oxford:* 332.3–181.9:112.4:111.781.
*Retrieval Terms:* slash decay; temperature; precipitation; decay rate.

A 34-year study of the condition of unburned logging slash in the mixed conifer type of the Sierra Nevada in northern California showed that breakdown and decay occurred at a much slower rate than has been reported for softwoods or hardwoods in other regions of the United States. Conclusions are based on 324 piles or strips available for part or all of this long-term study on the Stanislaus and Lassen National Forests.

Of primary importance in slash breakdown is the relation of climate to compaction (by winter snows), checking (particularly marked in open sunny spots), and decay by fungi. Secondary and minor elements in the physical breakup of slash, not measured in this study, are insects, cattle, and deer.

Temperature and moisture records from weather stations near the study plots were summarized for an 18-year period to show the significance of summer high temperature and low moisture, which are limiting factors on the spread and growth of the common decay fungi, in retarding decay of coniferous slash.

se-cedar had the lowest rate of decay, with ne, ponderosa pine, and white fir next in arge limbs or chunks of incense-cedar and ne were especially durable. Most prevalent ost active decay fungi were *Polyporus s, Fomes pinicola,* and *Lenzites saepiaria.* The of *Polyporus anceps* (in the California areas is a major reason for the slow rate at which h deteriorates.

alifornia, a span of at least 30 years was to lower the fire hazard from extreme ately after logging) to a rating generally ble to that in the prelogging condition.

ne Lassen, 29 years after logging, a sample en in lopped and scattered slash showed that wood approximated 43 percent of the original volume of the mixed pine, white fir and incense-cedar slash. Over a similar period of time, all test piles averaged 85 percent reduction in height and an estimated 60 to 70 percent reduction in volume. Pile subsidence was about 10 percent faster on the 123 piles on the Stanislaus than on the 83 Lassen piles, in part because of heavier snowfall in the Stanislaus area. Compact piles of slash –especially on north and northeast slopes in partial or full shade –decayed more rapidly than loosely piled slash in the same or drier environment. On open, sunny areas, breakup of scattered or piled slash by checking is an important factor during the initial 10 years after logging. White fir was most subject to breakup by cross checking, and incense-cedar was least affected over comparable periods of time; sugar pine and ponderosa pine were intermediate.

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1972. **Logging slash: its breakdown and decay at two forests in northern California.** Berkeley, Calif., Pacific SW. Forest & Range Exp. Stn. 11 p., illus.(USDA Forest Serv. Res. Paper PSW-83)

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# DOUGLAS-FIR IN NORTHERN CALIFORNIA:
## effects of shade on germination, survival, and growth

Rudolph O. Strothman

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Strothmann, Rudolph O.

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Effects of four light intensities on germination, survival, and early growth of Douglas-fir *(Pseudotsuga menziesii)* were studied on south-facing cutblocks in northwestern California. Tested were four shade intensities: 0, 25, 50, and 75 percent. On seeded spots, 50 percent shade resulted in greatest germination and survival, being significantly better than either no shade or 25 percent shade, but not better than 75 percent-shade. Shade did not significantly improve the survival of planted trees (either 1-0 or 2-0 age class), but growth was generally best on plots with least shade. Good survival on all treatments was probably due to careful planting, excellent stock, periodic weeding, and deep loam soil. An implication of these findings is that for direct-seeding, early shading is desirable, though difficult to achieve. A possible solution is to use a nurse crop converted to dead shade the spring after seeding.

*Oxford:* 174.7 *Pseudotsuga menziesii:* 232.324: 236.3: 232.33.

*Retrieval Terms: Pseudotsuga menziesii:* California (northwestern); artificial regeneration; light relations; protective shading; germination; survival; early growth; height increment.

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## ACKNOWLEDGMENT

I thank the personnel of the Hoopa Indian Reservation for their help in preparing the site, and in constructing and erecting the shading frames.

Getting satisfactory regeneration of Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco var. *menziesii)* on south-facing cutblocks in northwestern California is often a challenge to foresters. The hot, dry summers put a severe stress on the seedlings and many fail to survive the first growing season.

One technique for modifying the harsh environment is to provide shade for the seedlings. Effects of shade on Douglas-fir have been explored in several areas. In southwestern Oregon, Minore (1971) studied the survival and growth of Douglas-fir seedlings—60 growing under existing brush (live shade), 60 in the open, but shaded artificially with rocks, logs, or bark (dead shade), and 60 in the open without any shade. After two growing seasons, only 10 percent of the unshaded seedlings were still alive compared to 47 percent of those under the brush and 60 percent of those in dead shade. Shading did not significantly affect growth.

In California, the response of planted Douglas-fir to artificial shading was studied at three sites by the California Division of Forestry (Adams, Ritchey, and Todd 1966). Shade was provided by shingles from 5 to 7 inches wide, inserted in the ground on the south-southwest side of each seedling. At one site, differences in survival between shaded and unshaded trees were not significant except for spring-planted 1-1 stock. At the other two sites, the shaded seedlings had significantly better survival than did the unshaded ones.

In the Oregon Cascades, Franklin (1963) found, in studying Douglas-fir cutblocks of various shapes and orientations, that there was a definite relationship between the number of hours of shade from the adjacent stand and the number of seedlings which became established.

Effects of specific light intensities were investigated by Brix (1970) and Isaac (1943). In a British Columbia study Brix sought to determine what degree of shade would be most beneficial for the survival and growth of Douglas-fir seedlings. Six light intensities were tested, ranging from 10 to 100 percent of full natural light. Results indicated that full light should not be given new seedlings until 5 weeks after germination, or after mid-July. Best first-season growth occurred at 50 to 70 percent of full light.

At the Wind River Experimental Forest in Washington, Isaac grew seedlings under ventilated shade frames that admitted three different intensities of light. Expressed as percentages of full light, the midday averages were about 2 percent, 8 percent, and 15 percent (with respective maximums of 3, 10, and 20 percent). Also, seedlings were grown under full sunlight, and under three natural forest canopies where midday light values averaged about 1, 2, and 3 percent of full light.

In the controlled-shade portion of his study, Isaac found that the planted 2-0 trees survived best inside the frame which admitted the most light (i.e., an average of 15 percent midday light); best height growth also occurred under this treatment but the seedlings were etiolated. Next best survival and height growth occurred in full light, and this treatment also produced the healthiest and most vigorous seedlings. Under the heavier shade conditions, survival became progressively poorer and height growth also declined. Isaac concluded that Douglas-fir reproduction has little or no chance of successful establishment in anything less than 20 percent of full overhead light, even when there is no root competition, and that roughly 50 percent of full light is probably necessary for reasonable growth.

These studies of Brix and Isaac provided valuable information applicable to British Columbia and Washington. Whether these guides could be followed in California was not known. This paper reports a study to provide some answers about the influence of shade on Douglas-fir seedling growth and seed germination in northern California.

## STUDY SITE AND METHODS

The study aim was to determine which of four shade levels would promote the best survival and early growth of seeded and planted Douglas-fir on hot, dry, southerly aspects. On the Hoopa Indian Reservation (lat. 41°05′N, long. 123°37′W) in spring 1966, plots were laid out on a 50-percent, south-facing slope at about 3,000 feet elevation. The area had been logged in spring 1965 and the slash disposed of that fall. Douglas-fir was the main species present at the time of logging, but some tanoak *(Lithocarpus densiflorus* [Hook. & Arn.] Rehd.*)* and madrone *(Arbutus menziesii* Pursh*)* were present also.

The soil on the study site is 3 to 4 feet deep, with good internal drainage. It belongs to the Masterson series, derived from schistose sedimentary rock. The surface soil is a brown, moderately acid loam; the subsoil is a yellowish-brown, strongly acid gravelly loam.

Four levels of shade were tested: 0 (control), and 25, 50, and 75 percent. Shade for the study plots was provided by nailing redwood lath, at appropriate spacing, to a supporting framework *(fig. 1).* These lath strips were run north and south so that the sun's rays would not remain long on any given spot. No lath was used on the control plots, but they were enclosed around the sides with poultry netting to prevent deer and rabbits from damaging the seedlings. These plots were open on top, so that unobstructed sunlight would reach the seedlings except when the sun was low in the sky in the early morning or late afternoon.

Before planting and seeding, all plots were cleared of vegetation by hand scalping. They were subsequently kept weedfree by periodic removal of competing vegetation as it reappeared. This was done to prevent development of variable shading effects, which might be dense on one plot, and light or absent on another.

The four shading treatments were replicated three times, using a randomized block design. On each plot

**Figure 1.**—General view of the study site. Lath frames, left to right in foreground, provide 75, 50, and 25 percent shade.

**Figure 2**—Interior view of 25-percent shade frame just after planting. Each plot contained 2-0 seedlings, **right**, 1-0 seedlings, **center**, and screened seed spots, **left**.

10 1-0 and 10 2-0 Douglas-fir seedlings were planted with a planting hoe. Spacing was 2 feet between rows and 20 inches within rows.

In addition, 100 seeds were surface-sown on each plot in 10 groups of 10 seeds each. Each group was then covered with a dome-shaped hardware-cloth screen to protect the seeds from birds and rodents *(fig. 2)*. These screens were left in place until late summer of the first year, when germination was essentially completed and the screens were removed.

Before the end of the first growing season it became apparent that one of the 12 plots was being adversely affected by a large tanoak growing nearby. Although this tree did not shade the plot, the considerable extent of its root system had not been fully appreciated at the time of study installation. When it was later discovered how completely the soil on this plot was permeated by the far-reaching lateral roots of this tanoak, the reason for the unusually poor survival and growth of the Douglas-fir seedlings became evident. The data for this plot were therefore discarded and the missing data technique described by Snedecor and Cochran (1967) was used in the subsequent statistical analysis.

# RESULTS

## *Germination and Survival on Seeded Spots*

It was not feasible to follow germination and mortality on a daily or even weekly basis; thus, precise figures for total germination are not available. The June 9, 1967 seedling count, however, is probably a reasonable approximation, since most germination had taken place by then and mortality was not yet high. Using the seedling counts of June 9 as a base, the subsequent survival under the four shade levels was calculated *(table 1)*.

Germination was best on the plots with 50 percent shade, followed in order by the plots with 75 percent shade, 25 percent shade, and 0 shade. It should be recognized that protective hardware-cloth screens increased the shade actually received on the seed spots by an estimated 15 to 20 percent, but for

Table 1—*Average height growth and stem diameter of Douglas-fir seedlings of three age classes grown under four shade treatments, Hoopa Indian Reservation, California*

| Percent shade | Height growth | | Stem diameter |
|---|---|---|---|
| | First year | Second year | Second year |
| | *Feet* | | *Inches* |
| Seeded spots: | | | |
| 0 | – | – | – |
| 25 | 0.26 | 0.47 | 0.17 |
| 50 | .19 | .30 | .10 |
| 75 | .24 | .35 | .09 |
| 1-0 planted stock: | | | |
| 0 | .43 | .80 | .53 |
| 25 | .41 | .75 | .45 |
| 50 | .25 | .59 | .34 |
| 75 | .29 | .59 | .27 |
| 2-0 planted stock: | | | |
| 0 | .48 | .93 | .67 |
| 25 | .32 | .69 | .53 |
| 50 | .32 | .71 | .45 |
| 75 | .26 | .54 | .36 |

convenience and simplicity the plot-treatment percentages will be used in discussion. In these terms, germination on the various shade treatments was as follows: 50 percent shade, 15 percent germination; 75 percent shade, 11 percent germination; 25 percent shade, 5 percent germination; and 0 shade, 2 percent germination.

Subsequent survival was also best on the plots which had received 50 percent shade. At the end of two growing seasons under this treatment, 80 percent of the seedlings which had been present in June of the previous year were still alive and healthy. Next best survival was on the plots with 25 percent shade, where survival was 56.2 percent. Third best was on the plots with 75 percent shade (36.4 percent survival). On the unshaded plots no seedlings survived to the end of the second growing season.

For each 100 seeds sown, the numbers of live seedlings present after two growing seasons were: 0 percent shade, 0 seedlings; 25 percent shade, three seedlings; 50 percent shade, 12 seedlings; and 75 percent shade, four seedlings. Analysis of variance revealed that the effect of treatment on seedling numbers was statistically significant (5 percent level), primarily because of the superior germination and survival on the plots with 50 percent shade. This shading level produced significantly more seedlings than did either 0 shade or 25 percent shade, though not more than 75 percent shade. No other treatment differences were statistically significant.

## Survival of Planted Trees

Survival figures were computed for only the first 2 years because some seedlings were excavated from each plot at the end of the second and third years to examine root development and determine dry-weight.

Survival percent after 2 years ranged from 83 to 100 for the seedlings planted as 1-0 stock, and from 93 to 100 for those planted as 2-0 stock. For both age classes, 100 percent survival occurred only on the plots receiving 50 percent shade. Analysis of variance revealed, however, that the differences attributable to shade treatment were not statistically significant. Even the poorest survival was good when compared to that attained on operational planting jobs in northern California. Possible reasons for this are suggested in the Discussion section.

## Growth Responses

### Height

Height growth rather than total height was used as a basis of comparison because small treatment effects could be obscured by differences in initial heights of seedlings *(table 1)*.

In general, height growth appeared to be inversely proportional to the amount of shade received, with some exceptions. For both age classes of planted trees, best growth occurred on the unshaded plots. On the seeded spots, trees without shade did not survive beyond the first year. Best height growth for this age class occurred on the plots with 25 percent shade.

Analysis of variance revealed, however, that the differences in average height growth were not statistically significant. This may have been due to the considerable within-plot variation. Only treatment differences within each age class were tested, since the study was not designed to test differences between age classes.

### Stem Diameter

Like height growth, the growth of stem diameter was inversely proportional to the amount of shade received *(table 1)*.

Differences in average diameter under the various shade treatments were sizable, but analysis of variance revealed that they were statistically significant only for the 1-0 age class. The large within-plot variation on most plots precluded a sensitive test of stem-diameter response to different shade treatments.

For the 1-0 seedlings, there was no significant difference in average stem diameter between the 0 shade and 25 percent shade treatments, nor between the 50 percent and 75 percent shade treatments. There were significant differences, however, between either of the two lighter shade treatments and either of the two heavier ones.

## Root Length

At the end of both the second and third growing seasons, we carefully excavated a few seedlings of each age class from each plot *(fig. 3)* to examine root development and obtain oven-dry weight. The distance from the root collar to the tip of the longest root was measured, with gentle tension applied to straighten out major crooks.

For all age classes, average root length decreased as the amount of shade increased *(table 2)*. Only the third-year measurements of the 2-0 stock showed an interruption of the trend, the sample trees in the 25 percent shade treatment having a shorter maximum root length than those growing under the two heavier shade levels. This could easily have been due to sample variations, since different trees were used for each year's root measurements.

Analysis of variance revealed that differences in root length attributable to shade treatment were statistically significant (5 percent level) for both age classes of planted stock at the end of the second year but not the third. Root length differences among seedlings on the seeded spots were not statistically significant.

Within the 1-0 age group, there were no significant differences in average maximum root length among any of the three heavier shade levels (25, 50, or 75

Table 2 *Average length of the longest root for seedlings of three age classes grown under four shade levels*[1]*, Hoopa Indian Reservation, California*

| Percent shade | Second year | Third year[2] |
|---|---|---|
| | *Feet* | |
| Seeded spots: | | |
| 0 | | |
| 25 | 1.23 | |
| 50 | .96 | |
| 75 | .64 | |
| 1-0 planting stock: | | |
| 0 | 3.14 | 4.32 |
| 25 | 2.56 | 3.39 |
| 50 | 2.32 | 3.08 |
| 75 | 1.84 | 2.13 |
| 2-0 planting stock: | | |
| 0 | 3.26 | 4.38 |
| 25 | 2.63 | 2.74 |
| 50 | 2.52 | 3.07 |
| 75 | 1.99 | 2.83 |

[1]Based on 12 trees per treatment the second year, and 6 per treatment the third year.
[2]Seeded spots were observed for only 2 years.

**Figure 3**—Seedlings were excavated at the end of the third growing season to allow measurement of root length and plant weight. Part of the lath framework has been dismantled to make the excavation work easier.

percent shade). Only the unshaded seedlings had significantly longer roots than the others, and this only in comparison with trees receiving either 50 or 75 percent shade.

For the 2-0 age group, both the unshaded and the 25-percent-shaded seedlings had roots significantly longer than those grown under 75 percent shade. In addition, the roots of the unshaded seedlings were significantly longer than those of seedlings grown under 50 percent shade. Thus, for this age class, any two treatments which differed by at least 50 percent in shade level showed a significant difference in the average length of the longest root.

### Oven-Dry Weight

Dry weights of the tops and roots of excavated seedlings (12 per treatment for each age class the second year, and six per treatment for each age class the third year) were obtained by oven-drying the plant material to constant weight at 70°C. *(table 3).*

A clear pattern of decreasing dry-matter production with increasing shade is evident for all age classes of seedlings. On the seeded spots the dry-weight accumulation was more than five times as great for seedlings receiving 25 percent shade as for those receiving 75 percent shade. For the planted stock of both age classes the contrasts were somewhat smaller because these trees had grown under full light in the nursery for either 1 or 2 years before being outplanted under the various shade levels. Even so, at the end of 2 years in the field, the unshaded 1-0 seedlings averaged three times the dry weight of those which had received 75 percent shade. The unshaded 2-0 seedlings averaged more than three and one-half times the weight of those which had received 75 percent shade.

Although treatment means differed widely, variances within treatments were also large. Thus, analyses of variance showed that only for the 1-0 planting stock at the end of the second growing season were oven-dry weight differences among treatment means statistically significant (5 percent level). These differences were significant for all dry-weight variables (i.e., weight of top, weight of roots, and total weight).

For all three variables for this age group (1-0) after two growing seasons, the unshaded treatment produced significantly more dry matter than any other treatment. Also, the seedlings receiving 25 percent shade produced significantly more dry matter than those receiving 75 percent shade, except for dry weight of tops. Other differences among treatment means were not significant.

## Environmental Measurements

### Light

Since the lath strips in the shading frames were about one-quarter-inch thick, the bands of sunlight reaching the seedlings were full-width for only a short period each day, when the sun was most nearly overhead. At times other than midday the bands of sunlight were slightly narrower than the standard in proportion to the bands of shade. Thus, in the course of a day, the area inside the shading frames received somewhat more shade than the 25, 50, and 75 percent specified. Also, slight variations in plot orientation, as well as irregularities in the dimensions of the lath and a certain amount of warping, could be expected to cause minor variations in the amount of shade actually provided by the lath framework.

To find out how much light was actually reaching the seedlings within the shading frames, measurements of light intensity were made during a 6-hour period on a clear day in mid-July of 1967. Measurements were made simultaneously on all plots, using Ozalid paper light meters similar to the type described by Friend (1961). The penetration of light through a packet of this paper closely follows Lambert's law of absorption, and consequently the number of sheets bleached is proportional to the logarithm of the light energy received.

These measurements revealed that the actual amount of shade provided by the shading frames was 3 to 5 percent more than was intended. The nominal 25 percent treatment actually received about 30 percent shade; the 50 percent treatment received about 55 percent shade; and the 75 percent treatment received about 78 percent shade.

Also, during the first growing season, additional shade had been provided on the seeded spots on all plots by the hardware-cloth screens used to prevent seed losses to rodents and birds. No measurements of light intensity were made under these screens, since they had already been removed by the time measurements were taken. As noted earlier, however, these screens probably provided an extra 15-20 percent shade.

### Temperature

Maximum soil surface temperatures were measured by using heat-sensitive tablets with melting points o

Table 3—*Average oven-dry weight of seedlings of three age classes grown under four shade treatments,*[1] *Hoopa Indian Reservation, California*

| Percent shade | Second year | | | Third year[2] | | |
|---|---|---|---|---|---|---|
| | Top | Roots | Total | Top | Roots | Total |
| | *Grams* | | | *Grams* | | |
| Seeded spots: | | | | | | |
| 0 | | | | | | |
| 25 | 3.4 | 1.7 | 5.1 | | | |
| 50 | 1.0 | .7 | 1.7 | | | |
| 75 | .6 | .3 | .9 | | | |
| 1-0 planted stock: | | | | | | |
| 0 | 37.5 | 31.8 | 69.3 | 170.4 | 111.5 | 281.9 |
| 25 | 25.2 | 21.0 | 46.2 | 100.0 | 56.1 | 156.1 |
| 50 | 18.0 | 16.2 | 34.2 | 69.0 | 45.7 | 114.7 |
| 75 | 13.3 | 9.5 | 22.8 | 33.0 | 14.4 | 47.4 |
| 2-0 planted stock: | | | | | | |
| 0 | 62.7 | 41.3 | 104.0 | 428.7 | 240.9 | 669.6 |
| 25 | 42.8 | 28.2 | 71.0 | 171.2 | 94.6 | 265.8 |
| 50 | 42.6 | 27.8 | 70.4 | 94.7 | 49.4 | 144.1 |
| 75 | 17.0 | 11.5 | 28.5 | 70.2 | 35.8 | 106.0 |

[1] Based on 12 trees per treatment the second year, and 6 per treatment the third year.
[2] Seeded spots were observed for only 2 years.

113°, 125°, 138°, and 150°F. As before, no measurements were made under the hardware-cloth screens.

Weekly examinations of the tablets showed that the soil surface temperature during the first growing season exceeded 125° (but not 138°) on the plots with 75 percent shade and those with 50 percent shade; it exceeded 138° (but not 150°) on the plots with 25 percent shade and those with zero shade. During the second growing season the soil surface temperature exceeded 125° (but not 138°) on the plots with 75 percent shade; it exceeded 138° (but not 150°) on the plots with 50 percent shade; and it exceeded 150° on both the unshaded and the 25 percent shaded plots.

Midsummer air temperatures at one foot above the surface were also measured. Three recording hygrothermographs were installed on replication 3 for this purpose. Each instrument was placed on a level wooden platform to which was attached a sheet of heavy-gauge aluminum foil formed into an inverted U-shape to shield the instrument from rain, dust, dew, and the direct rays of the sun. The open ends allowed free circulation of air around the temperature-sensing element.

One instrument was kept on the unshaded plot, a second on the plot receiving 75 percent shade, and a third was alternated on a weekly basis between the plot receiving 25 percent shade and the one receiving 50 percent shade.

There was virtually no difference in the minimum temperature (either weekly lowest or mean minimum) between the unshaded and the 75-percent-shaded plots *(table 4)*. The highest temperature attained each week, however, averaged 7° F. higher on the unshaded plots than on the heavily shaded plots (104° vs. 97°), and the mean maximum temperatures for each week averaged 6° higher (99° vs. 93°). The weekly mean temperature (based on chart readings at 4-hour intervals) averaged 4° higher (72° vs. 68°) on

Table 4—*Air temperature means and extremes (at one foot above the ground) on the unshaded and the heavily shaded plots during summer 1967,*[1] *Hoopa Indian Reservation, California*

| Shade treatment and temperature characteristic | For 7-day period starting on | | | | | | | Average |
|---|---|---|---|---|---|---|---|---|
| | July 10 | July 17 | July 24 | July 31 | Aug. 7 | Aug. 14 | Aug. 21 | |
| | *Degrees F.* | | | | | | | |
| 0 percent shade: | | | | | | | | |
| Highest | 101 | 94 | 102 | 103 | 108 | 110 | 107 | 104 |
| Mean max. | 99 | 89 | 96 | 96 | 102 | 107 | 103 | 99 |
| Mean | 73 | 65 | 69 | 70 | 76 | 78 | 76 | 72 |
| Mean min. | 53 | 46 | 50 | 51 | 55 | 57 | 57 | 53 |
| Lowest | 48 | 41 | 46 | 46 | 52 | 52 | 54 | 48 |
| 75 percent shade: | | | | | | | | |
| Highest | 95 | 88 | 96 | 97 | 101 | 104 | 100 | 97 |
| Mean max. | 92 | 84 | 90 | 89 | 96 | 100 | 97 | 93 |
| Mean | 68 | 61 | 65 | 65 | 70 | 74 | 72 | 68 |
| Mean min. | 52 | 46 | 49 | 49 | 53 | 56 | 55 | 52 |
| Lowest | 48 | 41 | 44 | 44 | 51 | 51 | 54 | 48 |

[1] Based on data from recording hygrothermographs.

the unshaded than on the heavily shaded plot. The highest air temperature recorded on the unshaded plot was 110°F. and was reached several times during the week of August 14, 1967.

### Soil Moisture

During the first two growing seasons, soil moisture was determined gravimetrically for two different depths on each plot—6 to 8 inches and 16 to 18 inches. Samples were taken in May and again in August *(table 5)*.

Since analysis of variance revealed that shading treatment did not significantly influence soil moisture percent, no additional soil moisture parameters (such as percent moisture at wilting point or at field capacity) were ascertained.

For the most part, differences in average soil moisture at the two depths sampled on any given date were small. During the first growing season the samples came from soil essentially free of live roots, since the plots had been completely cleared of all vegetation prior to planting, and the roots of the planted seedlings had only begun their lateral extension. By August of the second year, however, root extension had increased considerably, and this probably contributed to the decreased soil moisture at both sampling depths by the end of the second summer. The precipitation pattern undoubtedly also contributed to this reduced second-year soil moisture by late summer, since no measurable amounts of rain fell in either July or August of that year, whereas about one-third of an inch had fallen in each of these months during the previous year.

Table 5—*Average*[1] *soil moisture under four shade treatmen sampling depths*[2] *during the first two growing seasons, Hoo Reservation, California*

| Percent shade | May 1966 | | August 1966 | | May 1967 | | Augu |
|---|---|---|---|---|---|---|---|
| | Shallow | Deep | Shallow | Deep | Shallow | Deep | Shall |
| | *Percent (by weight)* | | | | | | |
| 0 | 21.7 | 22.2 | 17.5 | 18.6 | 24.0 | 23.7 | 13. |
| 25 | 19.9 | 21.8 | 16.0 | 17.3 | 25.1 | 23.2 | 11. |
| 50 | 20.9 | 19.6 | 19.0 | 16.7 | 25.3 | 22.5 | 16. |
| 75 | 21.8 | 20.2 | 17.6 | 17.5 | 24.6 | 22.8 | 15. |
| Average | 21.1 | 21.0 | 17.5 | 17.5 | 24.8 | 23.1 | 13. |

[1]Average of six samples for each entry.
[2]Shallow sample depth, 6 to 8 inches; deep sample depth, inches.

## DISCUSSION AND CONCLUSIONS

The large within-plot variability in this study made the test of shade level less sensitive than I had hoped for. This variability was probably due mainly to genetic differences. Both seed and seedlings were from regular nursery seed lots, which normally consist of seeds from many trees in a given locality. Seed from a single tree would have been more desirable.

A larger sample size would also have improved the sensitivity of the test. This would have required the construction of larger shading frames, and thus increased installation costs, but, in retrospect, the added cost appears worthwhile.

The study nevertheless clearly demonstrated the value of shade for increasing the number of seedlings that will develop from seed and survive beyond the first growing season. Although the causes of mortality were not specifically identified in this study, heat or drought or both are probably the main causes for poor seedling establishment on the unshaded plots. Isaac (1938) found that a soil surface temperature of 123°F. is sufficient to injure Douglas-fir seedlings only a few days old. In laboratory studies, Silen[1] found that seedlings died at a temperature as low as 122°F. after 4 hours exposure in a water-bath apparatus. In the field he noted that the 138°F. temperature pellet appeared to be a reliable indicator of probable heat mortality on clearcut areas. In my study this temperature was exceeded on both the unshaded and the 25-percent-shaded plots.

The good survival of the planted trees of both age classes, regardless of shade level, was somewhat surprising since survival of unshaded Douglas-fir on south aspects has frequently been poor in operational plantings in northern California. Also, some of the research trials cited earlier had indicated that shading significantly improves the survival of planted Douglas-fir. The explanation for the good survival in the present study, regardless of shading treatment, probably lies in a combination of factors, including excellent planting stock, careful planting, removal of vegetative competition, and a deep, loamy soil.

[1]Silen, Roy Ragner. *Lethal surface temperatures and their interpretation for Douglas-fir.* 1960. (Unpublished Ph.D. thesis on file Ore. State Univ., Corvallis, Ore.)

Precipitation was considerably below normal for the 5-month period from May through September during both the first and second growing seasons. Thus, the good survival cannot be attributed to an unusually favorable precipitation pattern.

The main findings of the study were as follows:

- In direct seeding of Douglas-fir on a south aspect and a loamy soil in northwestern California, with competing vegetation periodically eliminated, the greatest number of seedlings became established with a shade level of about 50 percent (plus the shade provided by the protective hardware-cloth screens).

- Shade did not significantly improve the survival of good quality, carefully planted Douglas-fir seedlings (either 1-0 or 2-0 age class).

- Subsequent growth of the surviving seedlings averaged considerably better with 0 or 25 percent shade than under deeper shade. This pattern was readily apparent in terms of seedling dry weight, stem diameter, root length, and to a lesser degree, height growth. Although differences among treatment means were not statistically significant for every variable in every age class, the consistent over-all pattern of increased growth associated with the higher light intensities suggests that full sun to 25 percent shade is the most favorable environment for growth of Douglas-fir seedlings more than a few months old, where competing vegetation is periodically eliminated.

The implications of the first finding are that, for direct seeding of Douglas-fir, "clean" site preparation may not give the best results in terms of getting the greatest initial catch of seedlings per pound of seed sown. The problem is how to get a mineral soil seedbed (generally regarded as the most favorable) without eliminating the beneficial early shading effect which might be derived by leaving a light scattering of slash or other material on the cutover areas. One solution might be to sow a nurse crop, such as brown mustard *(Brassica juncea* [L.] Cosson.*)*, after slash disposal—a technique which proved successful on south slopes in Oregon (Chilcote 1957). The mustard plants must, however, be sprayed with herbicide the following spring to convert them to dead shade so they do not compete with the young conifer seedlings for moisture after the rainy season ends.

In evaluating the findings of this study, it must be remembered that the seeding and planting were done in a single year and on only one site. Additional testing on other sites and under other weather patterns is needed before we will know how widely these findings may be applied. Furthermore, tests in which the competing vegetation is not periodically removed would be worthwhile to observe seedling response to shade level under more typical field conditions.

## SUMMARY

Strothmann, Rudolph O.

1972. **Douglas-fir in northern California: effects of shade on germination, survival, and growth.** Berkeley, Calif., Pac. Southwest For. and Range Exp. Stn., 10 p., illus. (USDA Forest Serv. Res. Paper PSW-84)

*Oxford:* 174.7 *Pseudotsuga menziesii:* 232.324: 236.3: 232.33.
*Retrieval Terms: Pseudotsuga menziesii:* California (northwestern); artificial regeneration; light relations; protective shading; germination; survival; early growth; height increment.

Satisfactory regeneration of Douglas-fir *(Pseudotsuga menziesii)* on south-facing cutblocks in northwestern California is often difficult to achieve because hot, dry summers put severe stress on seedlings. Several studies of shade effects on Douglas-fir seedlings indicate that survival of unshaded seedlings is significantly lower than that of shaded ones.

This study was designed to determine which of four shade levels would promote best survival and early growth of seeded and planted Douglas-fir on hot, dry, southerly aspects in northwestern California. On the Hoopa Indian Reservation, in spring 1966, plots were laid out on a 50 percent south-facing slope at about 3,000 feet elevation, where

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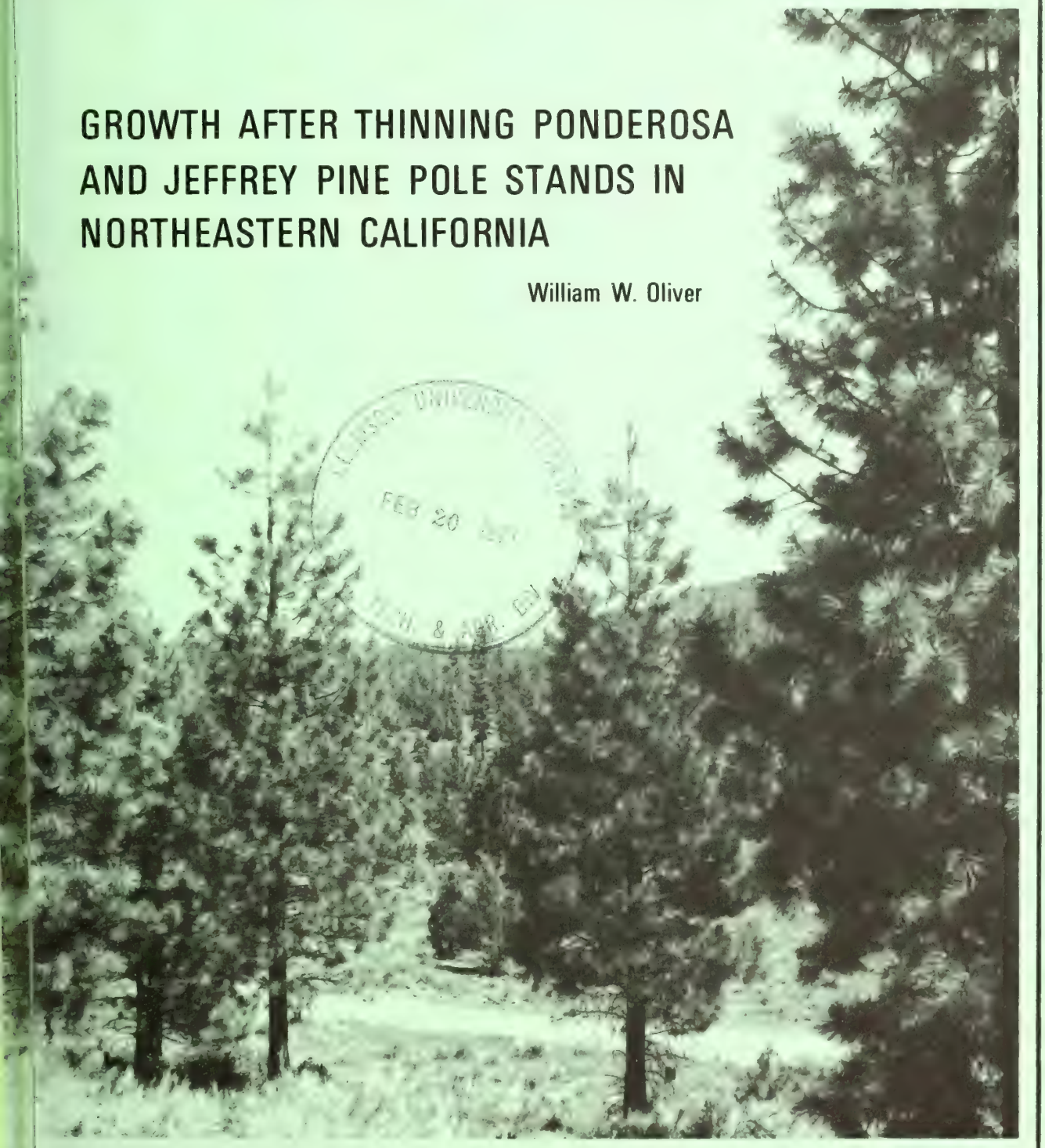
# GROWTH AFTER THINNING PONDEROSA AND JEFFREY PINE POLE STANDS IN NORTHEASTERN CALIFORNIA

William W. Oliver



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USDA FOREST SERVICE RESEARCH PAPER PSW- 85 /1972

Oliver, William W.

1972. **Growth after thinning ponderosa and Jeffrey pine pole stands in northeastern California**. Berkeley, Calif. Pac. Southwest Forest and Range Exp. Stn. 8 p., illus. (USDA Forest Serv. Res. Paper PSW-85)

Thinning ponderosa and Jeffrey pine pole stands (6 to 8 inches d.b.h.) on Meyer Site Classes IV and V land (site index 65 to 80) stimulates growth in diameter and height. This was concluded from data on 12 thinned plots scattered over northeastern California, in natural stands and in a plantation. Basal areas immediately after thinning ranged from 13 to 149 square feet per acre. Stands had many dissimilarities before thinning. Nevertheless, results allow the conclusion that thinning to about 80 square feet of basal area per acre will bring such stands to merchantable size as rapidly as possible with negligible loss of cubic-foot volume production.

*Oxford:* 174.7 *Pinus ponderosa* (794): 562.22 + 174.7 *Pinus jeffreyi* (794): 562.22.
*Retrieval Terms: Pinus ponderosa; Pinus jeffreyi;* thinning response; diameter growth; basal area; increment; stocking level; Lassen National Forest; Modoc National Forest.

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**The Author**

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## Acknowledgments

I am indebted to the California Region, U.S. Forest Service–especially timber management personnel of the Modoc and Lassen National Forests–for installing and maintaining the study plots upon which this report is based.

Controlling stand density by thinning is a vital part of the management of young stands. Thinning enables the forest manager to tailor the stand to fit his wood market and to reach that market sooner. East of the Sierra Nevada and Cascade Range in California, dense young stands of ponderosa pine *(Pinus ponderosa* Laws.*)* and Jeffrey pine *(Pinus jeffreyi* Grev. & Balf.*)* also need thinning to shield them from insect attack. More than 7,000 acres of this eastside forest type are thinned each year, but the optimum stocking level for timber production remains in question.

The Modoc and Lassen National Forests, faced with a large thinning program in pole-size ponderosa and Jeffrey pine, had little local data on growth following thinning. To obtain this information, about 20 thinning plots were established, either singly or in groups, over the past 25 years. Some of these plots served also to demonstrate National Forest thinning practices to the public.

This paper analyzes results from 12 plots with nearly complete records from which comparable data could be assembled. Dissimilarities still exist, but taken together these plots provide an estimate of growth of pole-size ponderosa and Jeffrey pine stands in northeastern California thinned to different stand densities. In addition, the data suggest the optimum basal area stocking for timber production.

## STAND CHARACTERISTICS

Eleven of the 12 thinning plots are in Modoc County on the Modoc National Forest; the other is in west-central Lassen County on the Lassen National Forest. Six plots are in a ponderosa and Jeffrey pine plantation on the west slope of the Warner Mountains near Sugar Hill Fire Lookout. The other six plots are in natural stands containing ponderosa pine with a few Jeffrey pine and ponderosa X Jeffrey pine hybrids.

At the time of thinning average stand age differed greatly between the plots in the Sugar Hill Plantation and the natural stands. The Sugar Hill Plantation was about 28 years old and the natural stands ranged from 50 to 70 years old *(table 1).*

Distribution of diameters also varied. As would be expected, the range of diameters in the Sugar Hill Plantation before thinning was narrow and the distribution slightly skewed toward larger diameters, whereas the range in the natural stands was wide and the distribution skewed toward smaller diameters. This difference was reduced but not eliminated by thinning.

Crowns of the leave trees in the natural stands were restricted by high initial stand densities—more so than the crowns of leave trees in the Sugar Hill Plantation. Growth response probably was delayed until the root systems and crowns expanded to reach their food-making potential as determined by the increased growing space following thinning. Fortunately, growth in all plots in the natural stands was measured at least twice in the years following thinning. Therefore, the first measurement data for plots in natural stands were not used in the analyses. The succeeding period should be more closely comparable to the full period after thinning plots in the Sugar Hill Plantation.

All plots but one contained an understory of basin sagebrush *(Artemisia tridentata* Nutt.*)* and tobacco brush *(Ceanothus velutinus* Dougl. ex Hook.*).* The remaining plot, Jelly Camp, lacked brush but did contain a dense understory of mule ears *(Wyethia mollis* Gray*).* In general, the amount of brush in the understory was light and inversely proportional to the overstory density.

Other stand characteristics differed between plots *(table 1).* Average stand diameters ranged from 5.5 inches to 9.3 inches breast height immediately after thinning, and site indices varied from 65 to 80 feet at 100 years (Meyer 1938).

**Figure 1—A,Sugar Hill Plantation Plot 3D was thinned in 1959 to 12.9 square feet of basal area** per acre; 13 years later it contained 36.4 square feet. **B**, Sugar Hill Plantation Plot 2D was thinned in 1959 to 24.4 square feet of basal area per acre; 13 years later it contained 54.2 square feet. **C**, Sugar Hill Plantation Plot 200 was thinned in 1961 to 60.8 square feet of basal area per acre; 11 years later it contained 97.8 square feet. **D**, Sugar Hill Plantation Control Plot contained 74.8 square feet of basal area per acre; 12 years later it contained 146.7 square feet.

Table 1—*Plot and stand characteristics at beginning of growth period after thinning of ponderosa and Jeffrey pine poles in northeastern California*

| Plot | Plot description | | | | Stand description on acre basis | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Year established | Growth period analyzed | Plot size | Site index | Stand age | Number of trees | D.b.h.[1] | Height | Basal area | Total volume |
| | | *Years* | *Acres* | | *Years* | | *Inches* | *Feet* | *Sq. ft.* | *Cu. ft.* |
| Sugar Hill 3D | 1959 | 11 | 1.36 | 75 | 27 | 43 | 7.4 | 23 | 12.9 | 124 |
| Sugar Hill 2D | 1959 | 11 | 2.00 | 75 | 27 | 80 | 7.5 | 22 | 24.4 | 235 |
| Sugar Hill 100 | 1960 | 10 | 1.00 | 70 | 28 | 100 | 6.7 | 21 | 24.4 | 204 |
| Washington Mt. | 1959 | 6 | .50 | 80 | 50 | 108 | 7.7 | 25 | 33.3 | 324 |
| Adin Pass | 1958 | 5 | .38 | 70 | 62 | 117 | 7.2 | 29 | 33.5 | 360 |
| Sugar Hill 200 | 1961 | 9 | 1.00 | 65 | 29 | 200 | 7.5 | 22 | 60.8 | 546 |
| Jelly Camp | 1963 | 5 | 1.16 | 65 | 65 | 190 | 7.8 | 46 | 62.4 | 885 |
| Sugar Hill Control | 1960 | 11 | 1.00 | 75 | 28 | 456 | 5.5 | 16 | 74.8 | 551 |
| Little Lavas No. 3 | 1945 | 16 | .26 | 65 | 68 | 221 | 8.2 | 34 | 81.1 | 1,244 |
| Sugar Hill 300 | 1960 | 10 | 1.00 | 75 | 28 | 300 | 7.2 | 24 | 85.5 | 784 |
| Hog Lake No. 1 | 1945 | 16 | .32 | 65 | 66 | 260 | 8.3 | 35 | 98.6 | 1,322 |
| Little Lavas No. 2 | 1945 | 16 | .12 | 65 | 69 | 312 | 9.3 | 35 | 148.6 | 3,034 |

[1]Quadratic mean.

# METHODS

The 12 plots selected for analysis had been hinned to a wide range of basal areas. They ranged rom 12.9 to 85.5 square feet per acre in the Sugar ill Plantation *(figs. 1A, B, C, D),* and from 33.3 o 148.6 square feet per acre in the natural stands.

Plot size and installation methods varied widely as ight be expected of plots established over so long a me span. Of the six plots in natural stands, five had o isolation strips and three had a scattered old-rowth overstory influencing part of the plot. Fortu-ately, because all trees were tagged and the original lots were at least one acre, smaller, homogeneous reas could be carved out for analysis of data.

All plots were thinned by the usual standard; that , the most vigorous, well-formed dominants and odominants were selected as leave trees, as far as this as compatible with reasonably uniform spacing. lots were thinned outside the growing season except or Hog Lake No. 1 and Little Lavas No. 3, which were thinned late in the growing season.

Slash disposal varied. All slash was removed from the Sugar Hill Plantation plots 100, 200, 300, and half of 2D, and at Washington Mountain and Adin Pass. At Jelly Camp, Little Lavas Nos. 2 and 3, Hog Lake No. 1, and Sugar Hill Plantation Plots 3D and half of 2D, the slash was lopped and scattered.

At each measurement, diameters of all trees were recorded to the nearest 0.1 inch. Every fifth tree was measured to the nearest 1 foot in height. Total cubic-foot volumes were found by determining the height/d.b.h. relationship for each plot at each measurement and interpolating volumes for the nearest 1 foot in height from *table 32* in Meyer's (1938) yield table for ponderosa pine. Volume estimates would have been better had upper stem diameter measurements been available. Nevertheless, the height/d.b.h. relationship accounts for most of the volume differences due to changes in stem form.

# RESPONSE TO THINNING

## *Diameter and Basal Area Increment*

Thinning had a marked effect on diameter growth, nd the effect was noticeable throughout the range of ost-thinning basal areas *(table 2).* Mean annual iameter growth was 0.46 inch for trees in the plot of west post-thinning basal area—12.9 square feet per re. Diameter growth values ranged downward at a eadily decreasing rate to 0.08 inch per year for trees the plot of highest basal area—148.6 square feet r acre.

The relationship of mean annual diameter growth stand basal area appears to be curvilinear and can expressed by the second degree polynomial:

Mean annual d.b.h. growth = 0.48344 - 0.00564 a. + 0.00002(b.a.)$^2$

which b.a. = basal area in square feet per acre. asal area is highly significant, explaining 91 percent the variation in mean annual diameter growth tween plots. Even though the relationship seems rvilinear, as experience tells us it must be, statisti-lly speaking the data do not depart significantly m linearity.

Trees in the plot thinned to 12.9 square feet of sal area probably are free-growing. They are growing in diameter at about the same rate as open-grown ponderosa pine.[1] Trees in the plots thinned to the next higher density—24.4 square feet—were probably competing for moisture and nutrients. Barrett (1968) found intertree competition at 26 square feet of basal area in a ponderosa pine pole stand in eastern Washington. Since, in the present study, only one plot was thinned to this lowest basal area (12.9 square feet), I cannot test the statistical significance of the increase in diameter growth at this level over the four plots thinned to about 30 square feet. Nevertheless, the actual effect of post-thinning basal area on mean annual diameter growth probably is similar to that shown in *figure 2A.*

Stand basal area slowed the annual diameter growth of the 43 largest trees per acre, also. Rather surprisingly, the influence was as great as that felt by the stand as a whole. The 43 largest trees per acre grew slightly faster in diameter—0.04 inch per year—but the reduction in diameter growth with increasing density was nearly identical to that in the entire stand.

Basal area growth per acre varied widely with stand basal area *(table 2).* No clear relationship was

[1]Unpublished data on file at the Pacific Southwest Forest and Range Experiment Station, Redding, Calif.

Table 2—*Growth after thinning ponderosa and Jeffrey pine pole stands in northeastern California*[1]

| Plot | Basal area at start of growth period | Total plot Mean annual growth in: | | | | 43 largest trees Mean annual growth in: | | |
|---|---|---|---|---|---|---|---|---|
| | | D.b.h. | Basal area | Height | Volume | D.b.h. | Basal area | Height |
| | *Sq. ft.* | *Inches* | *Sq. ft.* | *Feet* | *Cu. ft.* | *Inches* | *Sq. ft.* | *Feet* |
| Sugar Hill 3D | 12.9 | 0.5 | 2.1 | 1.4 | 34 | 0.5 | 2.1 | 1.4 |
| Sugar Hill 2D | 24.4 | .3 | 2.7 | 1.1 | 39 | .4 | 2.0 | 1.0 |
| Sugar Hill 100 | 24.4 | .3 | 3.1 | .9 | 41 | .4 | 1.6 | 1.1 |
| Washington Mt. | 33.3 | .3 | 3.2 | 1.6 | 49 | .4 | 1.7 | 1.6 |
| Adin Pass | 33.5 | .3 | 3.2 | 1.1 | 46 | .4 | 1.6 | 1.3 |
| Sugar Hill 200 | 60.8 | .2 | 4.1 | .7 | 55 | .3 | 1.3 | 1.0 |
| Jelly Camp | 62.4 | .2 | 2.6 | .8 | 49 | .2 | 1.0 | .7 |
| Sugar Hill Control | 74.8 | .2 | 6.5 | .9 | 79 | .2 | 1.0 | 1.2 |
| Little Lavas No. 3 | 81.1 | .1 | 3.1 | .5 | 76 | .2 | 1.2 | .8 |
| Sugar Hill 300 | 85.5 | .2 | 5.6 | .8 | 76 | .2 | 1.1 | .9 |
| Hog Lake No. 1 | 98.6 | .1 | 3.2 | .4 | 78 | .2 | 1.1 | .6 |
| Little Lavas No. 2 | 148.6 | .1 | 2.8 | .3 | 76 | .1 | .6 | .3 |

[1] All values on acre basis.

evident when all plots were analyzed together, probably owing to the disparity in diameter distributions between the Sugar Hill Plantation plots and the plots in natural stands. Basal area growth responded differently to stand basal area in the two sets of plots. At Sugar Hill basal area growth increased rapidly with increases in stand basal area throughout the range tested—12.9 to 85.5 square feet per acre. In the natural stands, basal area growth was about the same for all plots.

Further evidence can be found in the basal area growth response of the largest 43 trees per acre *(fig. 2B)*. Here where the distribution of diameters is about equal, both sets of plots behaved the same. Mean annual basal area growth per acre decreased consistently with increases in stand basal area.

## Height Increment

Height growth was sensitive to basal area. It ranged from 1.4 feet per year in the plot with lowest basal area—12.9 square feet per acre—to 0.3 feet per year in the plot with highest basal area—148.6 square feet per acre *(table 2)*. The height growth at Washington Mountain of 1.6 feet per year seems excessive and may be the result of faulty records. The height growth/basal area relationship appears to be slightly curvilinear and can be expressed by the second degree polynomial:

$$\text{Mean annual height growth} = 1.50274 - 0.01272\ \text{b.a.} + 0.00003(\text{b.a.})^2$$

in which b.a. = basal area in square feet per acre.

Similar to the diameter growth/basal area relationship, a curvilinear trend exists but the departure from linearity is nonsignificant, statistically. The curve explains 70 percent of the variation between plots—slightly more than the linear relationship. *Figure 2C* illustrates the effect of stand basal area on mean annual height growth, again assuming that the trees in the plot with lowest basal area are free-growing.

Thinning stimulated the height growth of the 43 largest trees on each plot, also. Their response was nearly identical to that of the stands as a whole. They averaged about 0.1 foot per year more in height growth over the range of stand densities.

In this analysis height growth response to basal area density appears to be real. Sometimes apparent height growth response is in reality a function of differences in average stand diameter after thinning. When a homogeneous stand is thinned to different densities, average stand diameter tends to increase with increasing thinning intensity. This can confound height growth data because the trees of larger diameter in a stand often grow faster in height. I found, however, no significant relationship between average d.b.h. of the plots immediately after thinning and their mean annual height growth. In the nine plots in which this relationship could be studied differences in average d.b.h. after thinning explained only 6 percent of the height growth variation between plots.

Height growth response to thinning has been highly variable as reported by others. It is well known

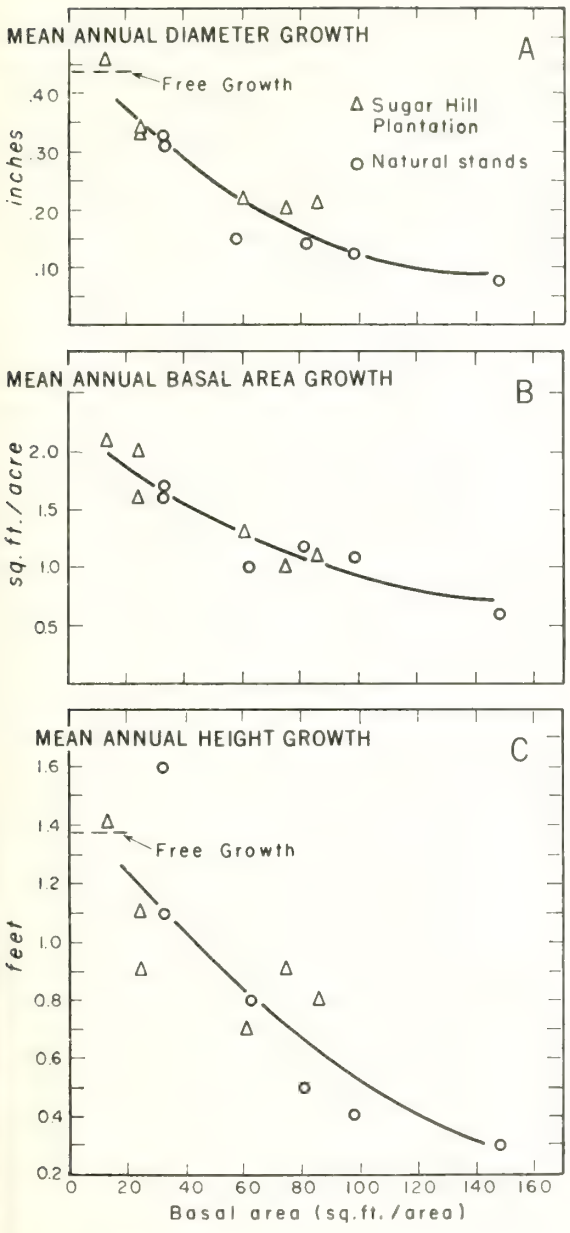


**Figure 2**—After ponderosa and Jeffrey pine pole stands in northeastern California were thinned, **A**, mean annual diameter growth was slower in plots with larger basal areas. **B**, mean annual basal area growth of the largest 43 trees per acre was slower in plots with larger basal areas. **C**, mean annual height growth was slower in plots with larger basal areas.

that height growth is less responsive to thinning than diameter growth. In fact, Barrett (1963, 1968) found no significant response from two thinning studies in pole-size ponderosa pine on comparable sites in the Pacific Northwest; neither did Schubert (1971), reporting on a thinning study in pole-size ponderosa pine on a slightly poorer site in northern Arizona. These three reports were based on the first 5 or 6 years following thinning of dense natural stands.

When height growth has been followed for longer periods, most investigators report a marked response (Stage 1958; Myers 1958; Boldt 1970). Three or 4 years often is needed for the released trees to build up their crowns sufficiently to produce the additional food required for increased height growth. This delay in height growth response is illustrated by the Washington Mountain and Adin Pass plots. Both were in heavily thinned dense natural stands. Height growth the second 5 years following thinning exceeded height growth the first 5 years by 87 percent and 59 percent, respectively.

## Volume Increment

Over half the plots were thinned so heavily that volume production suffered. Volume growth was only 34 cubic feet per acre per year in the plot thinned to 12.9 square feet of basal area per acre. Volume growth levels rose rapidly with increases in basal area up to about 75 square feet per acre *(fig. 3)* All plots with basal areas of about 75 square feet and above produced nearly identical volume growth. It varied between 75 and 80 cubic feet per acre per year.

The relationship appears to be curvilinear and can be expressed by the second degree polynomial:

Mean annual cubic foot volume growth = 19.537 + 0.934 b.a. - 0.0036(b.a.)$^2$

in which b.a. = basal area in square feet per acre.

In this equation basal area explains 88 percent of the variation in cubic-foot volume growth between plots. Nevertheless, further tests show that the data do not depart significantly from linearity, probably because there are not enough plots at the higher stand densities.

No data on upper stem diameters were available. Thus volumes were based solely on d.b.h. and total height of the tree. Differences in stem form between thinning intensities could alter the relationship somewhat, but I believe the inflection of the volume over stand density curve would be about the same.

Because cubic-foot volume production held constant over a wide range of basal areas—75 to 150 square feet per acre—the forest owner can manage his

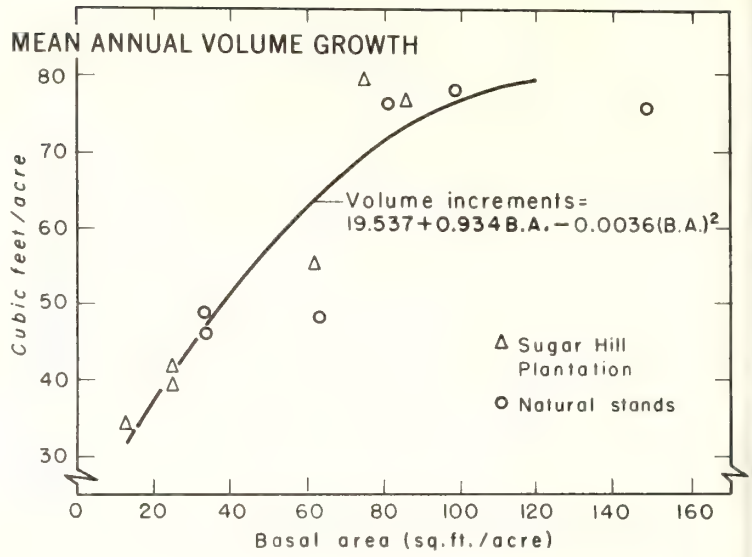


**Figure 3**—After ponderosa and Jeffrey pine pole stands in northeastern California were thinned, cubic-foot volume production was greater in plots of larger basal area, up to about 80 square feet per acre.

stands to fill a variety of wood markets with little or no loss of volume growth. In northeastern California where the market is for lumber, primarily, he may wish to bring ponderosa and Jeffrey pine pole stands to merchantable size as quickly as possible. *Figure 3* suggests that thinning to about 80 square feet of basal area per acre will meet this objective.

*Table 3* shows the average response in diameter, height, and volume growth throughout the range of plot basal areas studied.

Comparing normal yields (Meyer 1938) with the stand and growth data from this study helps to put the results in perspective. If an average site index of 70 feet at 100 years and equivalent stand diameters are assumed, and stand age is disregarded, approximate comparisons are as shown in *table 4*. These comparisons are rough because site quality and stand age varies widely between plots in this study. Nevertheless, with thinning to 80 square feet of basal area per acre (43 percent of normal), volume growth on these pole stands exceeds that shown for unmanaged stands by 18 cubic feet per year. This growth is achieved on 59 percent fewer stems.

Table 3—*Effect of stand basal area on diameter, height, and total volume growth following thinning ponderosa and Jeffrey pine poles in northeastern California*[1]

| Basal area (Sq. ft./acre) | Growth in: | | |
|---|---|---|---|
| | D.b.h. | Height | Total volume |
| | *Inches* | *Feet* | *Cu. ft./acre* |
| 20 | 0.38 | 1.3 | 37 |
| 40 | .29 | 1.0 | 51 |
| 60 | .22 | .8 | 62 |
| 80 | .16 | .7 | 71 |
| 100 | .12 | .5 | 76 |
| 120 | .10 | .4 | 79 |
| 140 | .09 | .3 | 79 |

[1] Average values from regression.

Table 4—*Average stand characteristics and volume growth of plots thinned to 80 square feet in present study compared with normal, unmanaged stands*[1]

| Source | Number of trees | Average d.b.h. | Basal area | Volume growth |
|---|---|---|---|---|
| | | *Inches* | *Sq. ft.* | *Cu. ft./yr.* |
| Present study | 261 | 7.5 | 80 | 71 |
| Unmanaged stands[2] | 632 | 7.3 | 184 | 53 |

[1] All values on acre basis.
[2] See Meyer (1938).

## Mortality

Only a few trees have died since thinning. An occasional tree of intermediate crown class died shortly after the natural stands were thinned, but they represent a negligible amount of volume or basal area loss. Mortality was surprisingly low considering that some plots were lightly thinned 26 years ago. No trees died in the plots in the Sugar Hill Plantation.

All plots but one were free of insect, disease, or animal damage. Substantial mortality is expected in the Sugar Hill Plantation Control Plot. Attacks by the mountain pine beetle *(Dendroctonus monticolae* Hopk.*)* have built up in recent years. No trees have succumbed so far, but elsewhere within the unthinned portion of the plantation, small groups of trees have died. These attacks on trees weakened by intertree competition are expected to increase unless the plantation is thinned.

# SUMMARY AND CONCLUSIONS

Oliver, William W.
1972. **Growth after thinning ponderosa and Jeffrey pine pole stands in northeastern California.** Berkeley, Calif. Pac. Southwest Forest and Range Exp. Stn., 8 p., illus. (USDA Forest Serv. Res. Paper PSW-85)

*Oxford:* 174.7 *Pinus ponderosa* (794): 562.22 + 174.7 *Pinus jeffreyi* (794): 562.22.
*Retrieval Terms: Pinus ponderosa; Pinus jeffreyi;* thinning response; diameter growth; basal area; increment; stocking level; Lassen National Forest; Modoc National Forest.

For control of stand density in ponderosa and effrey pine pole stands by thinning, information on ptimum stocking level for timber production is eeded. On 12 plots thinned to various densities, rowth results over periods of from 5 to 16 years ere analyzed. Plots included both natural stands and lantations in the Modoc and Lassen National orests. At time of thinning, plots differed in stand ge, distribution of diameters, and other haracteristics.

Basal areas after thinning ranged from 12.9 square eet to 85.5 square feet in plantation plots and from 3.3 to 148.6 square feet in natural stand plots. At ach measurement, records were taken of diameter of ll trees and height of every fifth tree; total cubic-ot volumes were calculated for each plot from eight/d.b.h. and Meyer's yield table.

The effect of thinning on diameter growth was oticeable throughout the range of basal areas (as easured after thinning). Mean annual diameter rowth values ranged downward from 0.46 inch per ear for 12.9 square feet basal area to 0.08 inch per ear for 148.6 square feet basal area; the relation of iameter growth to stand basal area appears curvi-near, and basal area explains 91 percent of the variation between plots. Influence of stand basal area on the 43 largest trees was similar to that on the entire stand. The relation of basal area growth to stand basal area was unclear for all plots together (probably owing to differences in diameter distribution), but for the largest 43 trees per acre, mean annual values decreased consistently with increase in stand basal area. The inverse relation of height growth to stand basal area was almost linear; basal area explained 70 percent of the variation. Volume growth levels increased with increase in basal area but leveled out at 75 square feet per acre basal area. Tree mortality was slight, and plots were free of insect or disease damage.

In spite of the difficulties of comparing plantation and natural stands, the plots demonstrate the potential diameter and height growth increase from thinning Meyer Site Class IV and V ponderosa and Jeffrey pine stands 6 to 8 inches d.b.h. in northeastern California. Thinning to about 80 square feet of basal area per acre will bring these pole stands to merchantable size as quickly as possible without sacrificing much cubic-foot volume production. At this optimum stand density for timber production, mean annual growth was 0.16 inch in diameter, 0.7 feet in height, and 71 cubic feet per acre.

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Oliver, William W.

1972. **Growth after thinning ponderosa and Jeffrey pine pole stands in northeastern California.** Berkeley, Calif. Pac. Southwest Forest and Range Exp. Stn. 8 p., illus. (USDA Forest Serv. Res. Paper PSW-85)

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*Oxford:* 174.7 *Pinus ponderosa* (794): 562.22 + 174.7 *Pinus jeffreyi* (794): 562.22.
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